LAKE WASHINGTON SHIP CANAL- HIRAM CHITTENDEN LOCKS-SHILSHOLE BAY

INVESTIGATIONS OF JUVENILE SALMON PASSAGE AND HABITAT UTILIZATION

Final Report of 2001 Investigations

Charles Simenstad, Jason Toft, Melora Haas,
Michele Koehler, and Jeff Cordell
Wetland Ecosystem Team
School of Aquatic and Fishery Sciences
University of Washington
Seattle, Washington
and
Kurt L. Fresh
NOAA-Northwest Fisheries Science Center
Seattle, Washington

Additional Study Collaborators:
Fred Goetz and Charles Ebel
U.S. Army Corps of Engineers, Seattle District
Dave Seiler
Washington Department of Fish and Wildlife
Steve Achord
National Marine Fisheries Service
Dean Park, Jim Sadler, Scott McCutcheon, and Brett Turley
Biomark Inc.
Kyle Bouchard, Peter Johnson
MEVATEC
Doug Houck
King County
Gail Arnold, Bruce Bachen, and Keith Kurko
City of Seattle

to

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Restoration General Investigation Study

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Introduction

This reports describes the results of our scientific investigations in 2001 on the influence of the structure and operations of the Hiram M. Chittenden Locks ("Locks") on the passage of juvenile salmon (*Oncorhynchus* spp.) between the Lake Washington Ship Canal ("Ship Canal") and Puget Sound, and aspects of distribution and habitat utilization by the juvenile salmonids and associated fishes in the estuary of Shilshole Bay immediately below the Locks. These studies are part of the comprehensive Lake Washington General Ecosystem Restoration General Investigation (GI) Study coordinated by the U.S. Army Corps of Engineers-Seattle District (Corps), in collaboration with local sponsors, since 1998.

Background

Since 1999, the Corps, City of Seattle, the King County, and other regional groups have been conducting environmental studies on the use and importance of the Ship Canal by juvenile salmonids, the passage of juvenile salmon through the Locks, and the potential for restoration of juvenile salmon habitat in the vicinity of the Locks. The studies are to lead to construction and/or operational improvements of the Locks to benefit Puget Sound ("fall" or "ocean-type") chinook salmon (*O. tshawytscha*), that have been listed under the Endangered Species Act (ESA).

The Locks serves as the highly modified, modern "neo-estuary" of the Lake Washington Basin, which is part of the Greater Lake Washington Watershed (encompassed by Water Resource Inventory Area [WRIA] 8; Fig. 1). Prior to completion of the Ship Canal and Locks in 1916, the

Figure 1   Location map of Cedar River-Lake Washington (Greater Lake Washington) watershed. Source: King County, http://splash.metrokc.gov/wlr/mapindex.htm.

Greater Lake Washington Watershed in conjunction with the Green-Duwamish and White rivers watersheds discharged into Puget Sound through the Duwamish River estuary. The modern Lake Washington Basin now includes lakes Union, Washington, and Sammamish, as well as their associated rivers, tributaries and wetlands, and discharges into Puget Sound via the Ship Canal and Locks. The Ship Canal includes Salmon Bay, the Fremont Cut, Lake Union, Portage Bay, the Montlake Cut, and ends approximately at the west margin of Union Bay (Fig. 2). The Locks (Fig. 3) are located at the western end of the Ship Canal within the city of Seattle, King

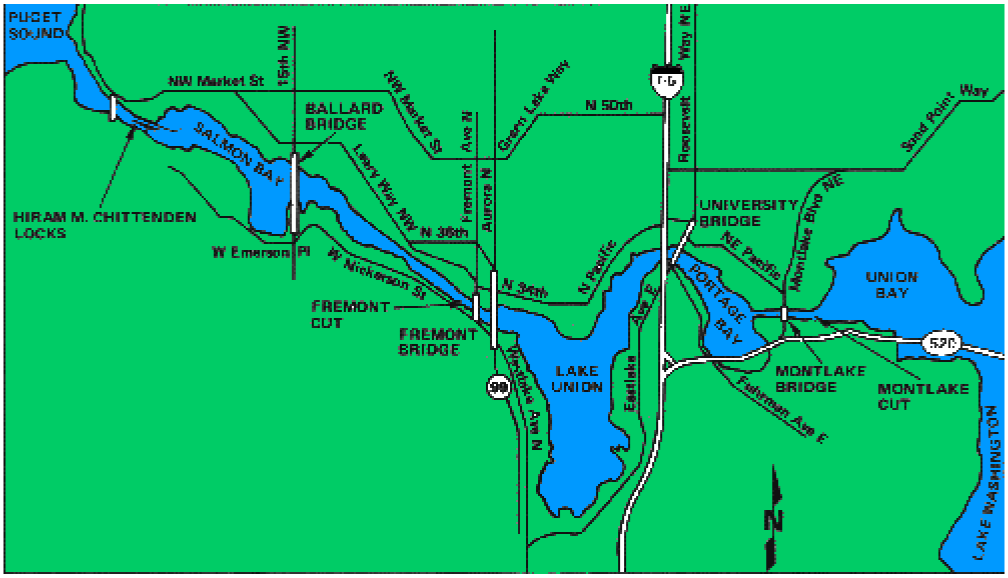

Figure 2 Position of Lake Washington Ship Canal and Hiram M. Chittenden Locks between Lake Washington and Puget Sound, within the City of Seattle, Washington. Source: USACE, http://www.nws.usace.army.mil/opdiv/lwsc/direct.html

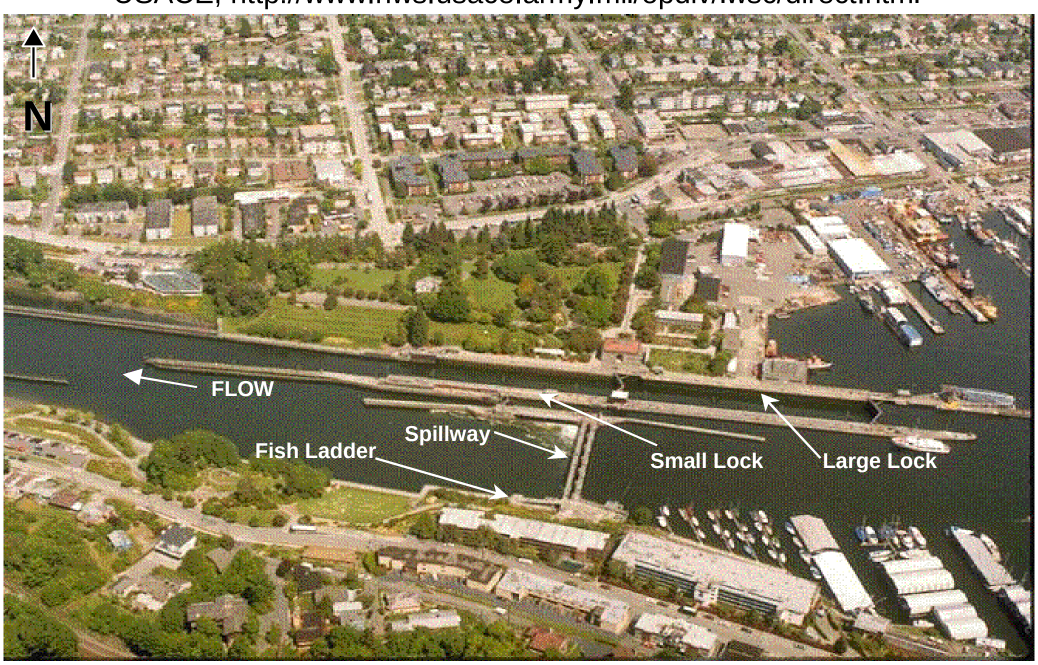

Figure 3 Oblique aerial photograph (looking north from, Shilshole Bay to left) of Hiram M. Chittenden Locks between Lake Washington and Puget Sound. Source: Fred Goetz, USACE.

County, Washington, at the entrance to Salmon Bay 1.9 km (1.2 mi) from Puget Sound. Shilshole Bay is the confined body of water, between the western terminus of the Locks and Puget Sound, that we consider the estuary. In terms of estuarine mixing of fresh water from the Lake Washington Basin and the saline waters of Puget Sound, the estuary is now a continuum that encompasses the Locks and the waters both west (Shilshole Bay) and under some conditions east (to and beyond Salmon Bay). Although immediately upstream of the Locks and the adjacent dam, which controls the water levels in the above mentioned lakes, is predominantly fresh, some salinity does intrude at depth into the Ship Canal and may extend into Lake Union during summer, low flow periods.

Problem Addressed by the Current Investigations

Extensive development of the Ship Canal shoreline and estuarine transition zone between the Locks and Puget Sound (Shilshole Bay) has been postulated to impact juvenile salmonid survival during this critical seaward migration and estuarine rearing stages of their early life history, and that measures toward recovery of salmon populations cannot be effective without consideration of estuarine habitat restoration. Although four species of anadromous salmonids that originate from the Lake Sammamish-Lake Washington watershed are abundant, concern is particularly focused primarily on the juvenile ocean-type chinook salmon that migrate to Puget Sound after comparatively short (weeks to months vs. years) freshwater rearing periods. In natural ocean-type chinook stocks, early ocean migration by the small juvenile salmon is strongly associated with shallow, shoreline habitats that are potentially vulnerable to impacts associated with loss or degradation of such 'natural' migratory corridors. Whether the extended rearing of juvenile chinook fry in Lake Washington provides a potential analog to estuarine rearing is under debate.

Juvenile salmon produced in the Greater Lake Washington Watershed must migrate through the Ship Canal and Locks in order to access Puget Sound and, ultimately, the North Pacific Ocean. In most years, in excess of 2.5 million smolts will migrate through the Locks. Detection of oligohaline-brackish (low salinity) waters by juvenile salmon migrating westward through the Ship Canal would denote estuarine rearing habitats, where several salmon species and life history types are known to rear for extended periods of time. However, increased stress and mortality during transit of the Ship Canal and Locks by juvenile chinook salmon has been implicated in the potentially impairment of their production in the Watershed. Factors considered to potentially contribute to increased mortality include:

1. Direct and indirect (delayed) consequences of descaling and other physical harm during passage through the Locks, as well as increased vulnerability to both fish and avian predators.
2. Decreased water flow increases migration rate (time) of juveniles between rearing in the Lake and Puget Sound, can increase exposure to predation.
3. Longer migration times result in smolts being exposed to higher water temperatures than they would normally migrate through.
4. Reduced flows available for operation of fish passage facilities at the Locks, and impairment of the freshwater transition zone in the estuary below the Locks, affect the estuarine survivability of the juvenile salmon at the transition to Puget Sound.

Juvenile salmon passage through the Locks is complicated by the various pathways they can take, and different levels of impact associated with each. There are 12 potential pathways for juvenile salmon to pass through the Locks to reach Shilshole Bay:

1. fish ladder;
2. spillway gates;
3. low-flow smolt bypass (smolt passage flumes);
4. “old” saltwater drain;
5. saltwater drain through the fish ladder auxiliary water supply;
6. volitional migration through the small lock miter gates;
7. volitional migration through the large lock miter gates.
8. entrainment into small lock culvert intakes;
9. entrainment into large lock culvert intakes (into the upper lock chamber)
10. entrainment into the small lock culvert intakes;
11. entrainment into large lock culvert intakes for the full lock chamber; and,
12. entrainment into the small culverts during downlock (of the upper or full lock).

Only the intake to the fish ladder, spillway gates, and the smolt passage flume (installed in 1995) are associated with low passage mortality. Prior to 1994, when smolts emigrated through the Locks during May-July, over 90% of the outflow passed through fish pathways that posed potentially significant mortality. After installation of smolt passage flumes, most of the total flow now passes through those pathways that are associated with lower mortality.

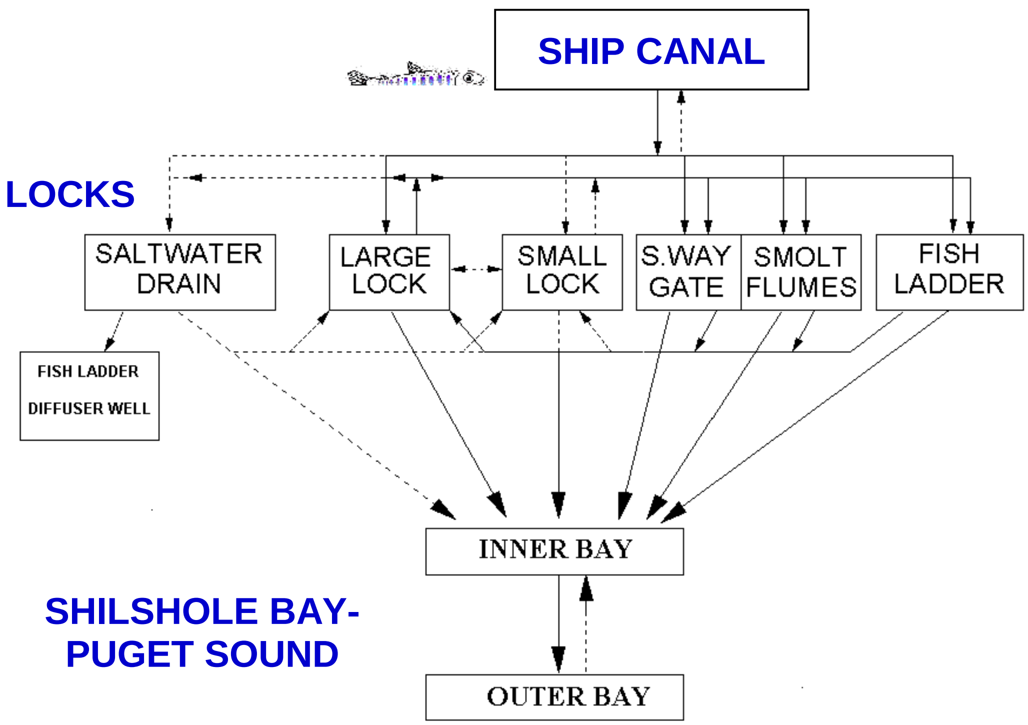

Figure 4 Conceptual model of observed (solid line) and potential (dashed line) downsteam movement of juvenile chinook salmon from Lake Washington Ship Canal through Hiram M. Chittenden Locks to Shilshole Bay and Puget Sound. Source: Fred Goetz, USACE.

Studies in the Ship Canal and Locks in 2001 were designed to verify earlier assumptions of lower fish mortality under the new structural and operational modifications of the Locks and to provide a broader context of the mortality factors at the Locks relative to the migration of juvenile salmon from their source watersheds, Lake Washington, and the Ship Canal. To this purpose, an important element of the study involved interception below the Locks (Fig. 5) of juvenile salmon that had been implanted with PIT tags as they emigrated from the Cedar River and Bear Creek into Lake Washington, and at the eastern end of the Ship Canal (Montlake), at an intermediate location (Lake Union). This would include tagged fish that were both detected at the smolt flumes and in-lock sampling, as well as those that moved through the locks undetected. A total of 18,643 juvenile salmon were PIT-tagged within the Greater Lake Washington Watershed, of which 3,749 juvenile chinook originated from the Cedar River and Bear Creek and 4676 from the Issaquah Hatchery (Table 1). In addition, 7,723 juvenile salmon captured and released in the Montlake and Lake Union area, or at the METRO Laboratory region, of the Ship Canal were also be PIT-tagged, 4,927 (181 natural, 4,746 hatchery) were chinook.

Of the potential pathways through the Locks, only the fish ladder, smolt passage flumes and large locks were monitored for smolt passage. Add ional data from sampling in 2000 provided some information on fish passage through the saltwater drain and spillway gates. While this monitoring implies unidirectional passage, some smolts actually reenter the Locks during uplock (moving boats from Shilshole to the Ship Canal) operations and cycle back through the Ship Canal, resulting with variable detection in the different pathways (where detection is possible).

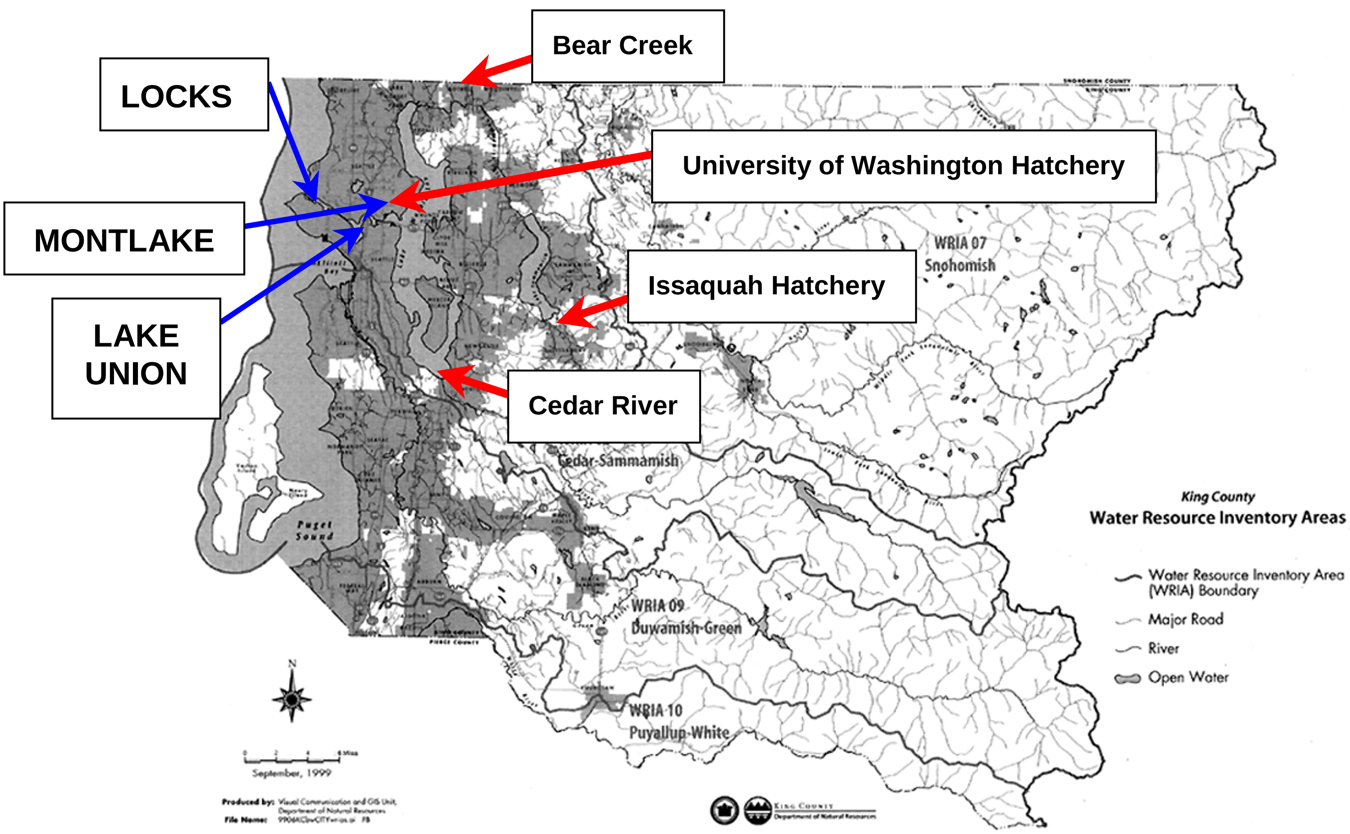

Figure 5 Sources and interception of PIT-tagged juvenile salmon passing through the Lake Washington Ship Canal and Locks. Source: map from King County website, http://splash.metrokc.gov/wlr/mapindex.htm

Table 1 Sources and numbers of PIT-tagged juvenile salmon entering the Greater Lake Washington Watershed or tagged and released in 2001; locations are identified in Fig. 5. From DeVries (2001).

SPECIES	ORIGIN	Issaquah Creek Hatchery	Bear Creek	Cedar River	Montlake Cut	UW Hatchery	Lake Union	METRO Laboratory
Chinook	Natural	--	2132	1550	67	--	114	--
	Hatchery	4676	--	67	635	2015	1892	204
Coho	Natural	--	1011	1235	37	--	239	--
	Hatchery	--	12	--	5	--	333	--
Sockeye	Natural	--	--	8	164	--	2219	--
Steelhead	Natural	--	3	22	--	--	3	--

Primary Scientific Questions

In order to obtain information critical for assessing potential impacts to salmon approaching and passing through this highly-modified, "neo-estuary" environment, we required information about the temporal and spatial patterns of juvenile salmon migration, their migratory environment (circulation, water salinity and temperatures), and juvenile salmon diet composition and available food resources (e.g., benthic invertebrates, zooplankton, terrestrial insects) relative to structure and operations of the locks. In addition to this focus on juvenile chinook, the occurrence of other salmon and non-salmonid fish species is also of interest. Information on the (mapping of) the composition of anthropogenic and natural shoreline habitat in Shilshole Bay and the adjoining nearshore environs, which is scheduled to be gathered at a later date, would provide additional information that would lend further interpretation of these data.

Past and on-going studies of juvenile chinook passage through the Locks is addressing a number of critical questions about the impact of the urbanized watershed and the highly modified urban/commercial waterway on juvenile chinook and other salmonids migrating to Puget Sound. Within the context of the comprehensive USACE GI, the Corps, sponsors and other participants in programmatic approaches to ESA issues have pursued six questions related to the estuarine transition of juvenile salmon through the Locks to Puget Sound through Shilshole Bay:

1. **What is the effect on juvenile salmon, and especially ocean-type chinook salmon, of different pathways and timing of passage through the Locks?**
2. **What are the natural shoreline "habitat" (depth and substrate regime; water quality and other characteristics; food resources; predation refuge) and modifications (e.g., over-water structures, lighting, etc.) conditions in the Shilshole Bay estuary, both above and below the Locks that would support juvenile chinook salmon?**
3. **How does the effect (including: Lake Washington Ship Canal level, flow and temperature; flow pathways through the Locks, and salinity intrusion and distribution) of water availability (climate and human management influences on watershed runoff available for flow at the Locks) and quantity (water conservation actions) affect the performance of juvenile chinook passage through the Shilshole Bay estuary?**

4. **What is the extent (pattern of movement, habitat characteristics) and timing (residence time, transition rate) of juvenile salmonid use and movement in Shilshole Bay below the Locks, prior to movement into Puget Sound?**
5. **What modifications of the Locks and operations and of habitat availability and attributes above and below the locks would significantly increase the survival of juvenile salmonids migrating into Shilshole Bay?**
6. **How do juvenile salmonids and forage fishes other than those originating from the Lake Sammamish-Lake Washington watersheds utilize Shilshole Bay?**

Goal and Objectives

The goal of this project is to ***assess within the comprehensive GI studies the function and limitations of Shilshole Bay (estuary, as defined above) in supporting juvenile salmonids, especially chinook salmon, and to provide information for enhancement***. This includes collecting information to assess impacts of changes to the estuary and to propose restoration strategies to minimize and resolve impacts in the western Ship Canal-Shilshole Bay region and to help with chinook salmon recovery. Potential restoration strategies primarily include construction of habitat within the greater Shilshole Bay estuary, changes to the locks structures, and/or changes in operations of the locks. These questions and considerations are optimally addressed by organizing a comprehensive study around the following two scientific objectives:

I. Juvenile salmon pathways, behavior and performance

Determine the patterns and performance of juvenile salmon passing through the various alternate pathways of emigrating from the Lake Washington Ship Canal through the Locks into and during their residence in the greater Shilshole Bay estuary.

II. Lake Washington Ship Canal and Locks affects on the environment of the greater Shilshole Bay estuary

Determine how the structure and operation of the Lake Washington Ship Canal and the Locks affects important features of the environment to which juvenile salmon respond in the greater Shilshole Bay estuary.

These study objectives are designed to generate a mechanistic, rather than a descriptive, understanding of how juvenile salmon respond to the composition, arrangement and quality of habitat available to them in traversing the Ship Canal and Locks to Puget Sound, such that the causes for documented fish behavior and performance can be better understood and changes in habitat in the "neo-estuary" and Shilshole Bay may be reliably predicted.

Study Tasks

Task I.A Recover in Shilshole Bay PIT-tagged juvenile Chinook salmon that have used alternative pathways through the Locks

Conduct high intensity, low frequency sampling to recover the maximum number of PIT-tagged juvenile chinook salmon during peaks in their migration from the Lake Washington Ship Canal through the Locks to Shilshole Bay.

This study took advantage of the broader Lake Washington GI study elements that involved sampling of juvenile chinook salmon that have been tagged with PIT tags and released in a variety of locations within the Greater Lake Washington Basin (see Background above). Detection, either manually or by PIT tag detectors, occurred during their passage through the Lake Washington Ship Canal and the Locks. Experience from prior years' sampling suggested that juvenile salmon, and particularly chinook, would likely pass through the locks in pulses. In order to maximize recapture/detection efficiency for the PIT-tagged fish, sampling below the Locks was designed to focus continuous sampling for a sort "blitz" period coincident with the most prominent pulse of fish movement through the western terminus of the Ship Canal and the Locks.

Task I.B Assess the overall use of Shilshole Bay by juvenile salmon, irrespective of their origin, and related (potential predators and competitors) fishes

Conduct low intensity, high frequency "background" sampling of all species of fish in several "indicator" locations/habitats in Shilshole Bay.

Extended detection of PIT-tagged Lake Washington and Lake Sammamish juvenile chinook beyond the period of high intensity/low frequency sampling, as well as detection of other salmonids and forage fishes, in Shilshole Bay involved less intensive but more continuous sampling. Pilot sampling in 1999 and beach seining indicated juvenile salmon occurred in the Shilshole Bay region into late August, when sampling was terminated. Similarly, systematic beach seine sampling by the Muckleshoot Indian Tribe (MIT) in 2000 implied extended abundance of juvenile chinook in the inner Bay. Continuous sampling provided several types of information that the "blitz" sampling did not, most notably (1) a direct comparison between this (low water flow) year and the prior year's results, (2) systematic sampling that can be used to estimate fish densities, (3) continuous data on the presence of juvenile salmon and other species throughout the western greater Shilshole Bay estuary, and (4) recaptures of PIT-tagged juvenile salmon beyond those recaptured during the blitz sampling proximal to the Locks.

Task II.C Document juvenile salmon diet and prey resources in the greater Shilshole Bay estuary.

Address the natural and unique capacity of the greater Shilshole Bay estuary to support foraging by juvenile salmon that are both migrating through the Ship Canal and Locks as well as rearing in the estuary. An effort will be made to also collect diet and prey resource information above the Locks.

The purpose of this task was to determine to what extent and under what conditions the sources of prey resources for juvenile salmon above and below the Locks originates from allochthonous production in the Lake and the Ship Canal or from autochthonous prey production in estuarine habitats. Preliminary data from the 1999 UW-WDFW pilot sampling of juvenile salmon in the western estuary indicated that juvenile chinook and other salmon utilized four categories of prey resources, three of which include natural estuarine organisms and a third which is atypical: (1) epibenthic crustaceans (amphipods, isopods, harpacticoid copepods); (2) pelagic invertebrates (copepods, amphipods) and fish; (3) neustonic (drift) insects; and (4) pelagic freshwater zooplankton (particularly the cladocerans *Daphnia* spp.). However, no fish were collected for diet analyses from the Ship Canal during the 1999 studies. The occurrence and prominence of the atypical freshwater zooplankton was highest in fish caught closest to the Locks, suggesting that either fish were feeding on the cladocerans as they were swept into and stressed by the more saline waters below the Locks or the fish had fed extensively on them in freshwater environs in the Ship Canal and were captured soon after their passage through the locks.

Methods

Task I.A Recover in Shilshole Bay PIT-tagged juvenile Chinook salmon that have used alternative pathways through the Locks

Blitz sampling was designed to sample juvenile salmon as continuously as possible within close proximity (e.g., east of the BN railroad bridge) of the Locks (Fig. 6). We conducted systematic sampling of salmon in intertidal/shallow subtidal habitats with a 37-m floating beach seine according to the standardized *Estuarine Habitat Assessment Protocol* (see insert, Fig. 6; Simenstad *et al.* 1991). When adhering effectively to that protocol, the method results in sampling of an area of approximately 520m^2. Intensive sampling below the locks occurred diurnally (14-16 hr per day) during peak juvenile chinook migration, based on information on fish passage in previous years, the apparent timing of fish movement through the Ship Canal and smolt counts at the Locks.

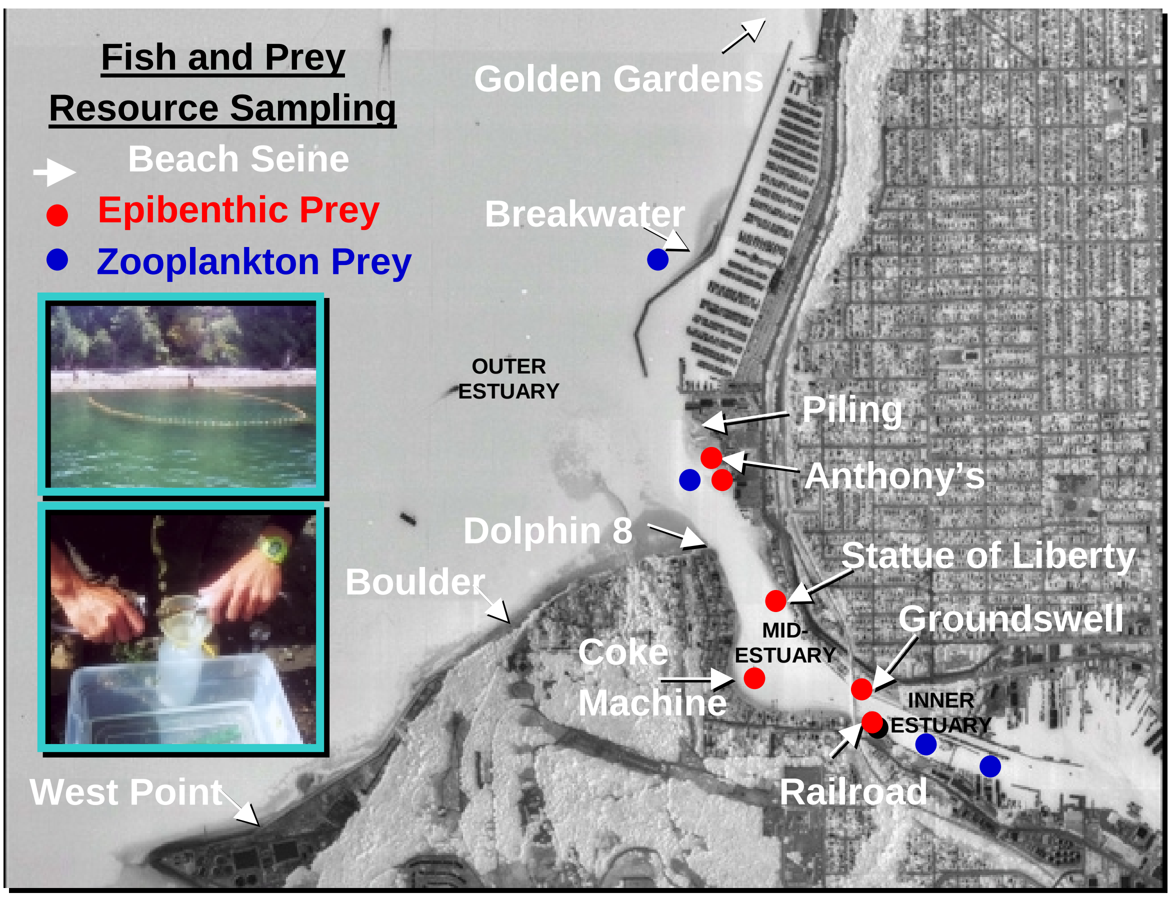

Figure 6 Sampling sites for fish and prey resources in the region of Shilshole Bay and adjoining nearshore waters of Puget Sound, and including one (zooplankton) station upstream of the Hiram M. Chittenden Locks.

Based on these indicators, sampling occurred during the week of 18-22 June. The blitz sampling was also coordinated with both the seining in the large Lock chamber and the lower intensity, higher frequency sampling (Task I.C) in the lower Shilshole Bay estuary. Field personnel were responsible for two discrete tasks: (1) beach seining and (2) PIT tag detection.

Task I.B Assess the overall use of Shilshole Bay by juvenile salmon, irrespective of their origin, and related (potential predators and competitors) fishes

The primary focus of this sampling was to characterize juvenile salmon residency in the western margin of the greater Shilshole Bay estuary but were also designed to document seasonal changes in intertidal fish assemblages, the life history and size structure of dominant species, samples of (via gastric lavage) prey consumed by juvenile salmon and recovery of PIT-tagged fish beyond the spatial and temporal scope of the blitz sampling. To assess the overall use of Shilshole Bay and adjoining nearshore waters of Puget Sound, we continued the same sampling protocol at representative sites within the inner Bay and outer Bay similar to that deployed by Footen (MIT) in 2000. As in Task 1.A, we adopted the 37-m floating beach seine protocol because it provided a broader comparison with other datasets that we and other investigators have generated from around Puget Sound and coastal Washington estuaries for several decades. Sampling occurred biweekly at the eleven sites (Fig. 6), initiating on April 30 and terminated on October 11. The sites were selected for catch consistency (low variability) based on analysis of the 1999 (UW-WDFW) and 2000 (Footen) catches. While the *Estuarine Habitat Assessment Protocol* recommends sampling at low tide, beach characteristics (e.g., boulder fields and rubble, pilings, etc.) prevented us from sampling all sites accordingly; however, each site was sampled consistently throughout the sampling period.

Task II.C Document juvenile salmon diet and prey resources in the greater Shilshole Bay estuary.

We documented diet composition of a representative subsample of juvenile salmon coincident with both Task 1.A and Task 1.B sampling of Shilshole Bay and adjoining nearshore Puget Sound waters (Task 1.B). Fish collected with the beach seining collections were sampled non-destructively by gastric lavage. This method consisted of placing fish in a bucket of seawater with a small amount of the anesthetic MS-222 for approximately 30-60 seconds. Each fish was removed from the bucket and fork length measured; gut contents were then removed using a modified garden pump sprayer with a custom nozzle and filtered seawater (see insert, Fig. 6; Hartleb and Moring 1995). Contents were washed into a fine mesh sieve and fixed in 10% formaldehyde solution. Fish were immediately placed in a bucket of seawater for recovery (approximately 2-3 minutes), and then released.
Fish stomach contents were later analyzed in the laboratory, and prey items ranked based on modified Index of Relative Importance values (IRI; Pinkas *et al.* 1971; Simenstad *et al.* 1991):

IRI = % frequency of occurrence X [% numerical composition + % gravimetric composition]

All sampling techniques were monitored for any potential injury to salmonids, which could include entanglement in nets or over-anesthetization with MS-222. Mortality was negligible.

To assess relative prey availability at decreasing distance of influence of the Locks influx of freshwater zooplankton, we conducted biweekly sampling of pelagic zooplankton in the water column and epibenthic prey resources on intertidal substrates. In addition supplemental sampling was conducted to assess the potential contribution of neuston (surface) organisms, which often includes drift insects that appear prominently in juvenile chinook salmon diets. Zooplankton sampling was conducted according to the *Estuarine Habitat Assessment Protocol* (Simenstad *et al.* 1991) using a 0.5-m "Puget Sound" ring net of 0.500-mm Nitex mesh. The net was lowered slowly to the bottom and then pulled vertically through the entire water column. The net was washed down and the collected organisms removed from the cod end of the net and preserved in the field with 10% buffered Formalin. Three replicate plankton hauls were obtained from each station, from points aligned laterally cross-channel.

Sampling of surface benthic and epibenthic invertebrates was conducted with a vacuum filtration device (Arrol 1995; Major et al. 1997; Koehler 2002). A 0.05m^2 area PVC tube is lowered slowly to the bottom in the intertidal beach region within the 0.0-m to 0.3-m MLLW tidal elevation. A vacuum wand gently disturbed the surface sediment and the water column within the tube filtered through a 0.250-mm mesh sieve for one minute, or until the filter was clogged with sediment. Five replicate samples were collected from haphazardly selected positions along the same intertidal elevation. Samples were bottled and preserved in the field with 1o% buffered Formalin.

Neuston sampling was conducted with a floating, 0.4-m x 0.2-m rectangular neuston net equipped with 0.130-mm Nitex mesh (Locke and Corey 1985; Brodeur 1988; Koehler 2002). The net was deployed alongside an outboard-powered boat 30 m offshore of the intertidal epibenthic sampling sites. Only one neuston tow was obtained at each site. Approximately 11.5m^2 of the surface waters ~10-cm deep was sampled during each tow.

Results

While the *Goals and Objectives* and *Methods* were described above according to the study's tasks, we present the following results by distribution and relative abundance of fishes, including juvenile salmon, in Shilshole Bay and adjacent nearshore Puget Sound waters and specific information on the immigration and residence time, diet and prey resources of juvenile salmon in the Bay.

Fish Distribution and Relative Abundance in Shilshole Bay and Adjacent Nearshore Puget Sound Waters

Thirteen taxonomic categories of fishes were captured at the eleven sites along the Shilshole Bay-nearshore Puget Sound estuarine gradient (Table 2). Shiner perch dominated the catches (34%) but juvenile salmon were the second most prominent (11%) taxa (Fig. 7). The distribution of fish taxa over time (Fig. 8) illustrated that juvenile salmonids were most prominent early in the sampling period, peaking at a pooled mean of ~120 fish per seine haul in early June, while shiner perch, sculpins and threespine stickleback (after mid-July) were common components of this nearshore fish assemblage throughout the sampling period. Other prominent species, such as Pacific herring and tube-snout, appeared prominently for only 4-8 weeks, predominantly in mid-summer. As a result of these patterns, peak densities of nearshore fishes susceptible to our floating beach seine methodology though Shilshole Bay and the adjoining nearshore Puget

Table 2 Fishes documented from distributional sampling along the Shilshole Bay-nearshore Puget Sound estuarine gradient pooled over 11 sampling sites, April – October 2001. CPUE = Catch Per Unit Effort in 37-m floating beach seine, which samples ~520 m^2.

Taxa	Common Name	Mean Pooled CPUE	Highest Pooled CPUE
Clupea harengus pallasi	Pacific herring	21.95	136.91
Salmonidae (juvenile)	salmon	15.45	117.0
O. nerka	sockeye salmon	0.07	0.09
O. keta	chum salmon	7.77	83.45
O. kisutch	coho salmon		1.35
O. tshawytscha	chinook salmon	6.97	32.55
Osmeridae (e.g., *Hypomesus pretiosus, Spirinchus thaleichthys*)	smelts	2.58	19.64
Aulorhynchus flavidus	tube-snout	6.51	46.55
Gasterosteus aculeatus	threespine stickleback	11.35	36.72
(other) Embiotocidae (e.g., *Embiotoca lateralis*)	surfperches	2.44	8.45
Cymatogaster aggregata	shiner perch	49.52	213.55
Stichaeidae (e.g., *Anoplarchus purpurescens, Lumpenus sagitta*) and Pholidae (e.g., *Pholis* spp.)	pricklebacks and gunnels	2.70	9.27
Ammodytes hexapterus	Pacific sand lance	3.19	21.93
Cottidae (e.g., *Leptocottus armatus, Artedius* spp.)	sculpins	15.01	47.09
Pleuronectes vetulus	English sole	5.08	16.09
Plathichthys stellatus	starry flounder	3.90	7.55
Other species		1.10	3.57

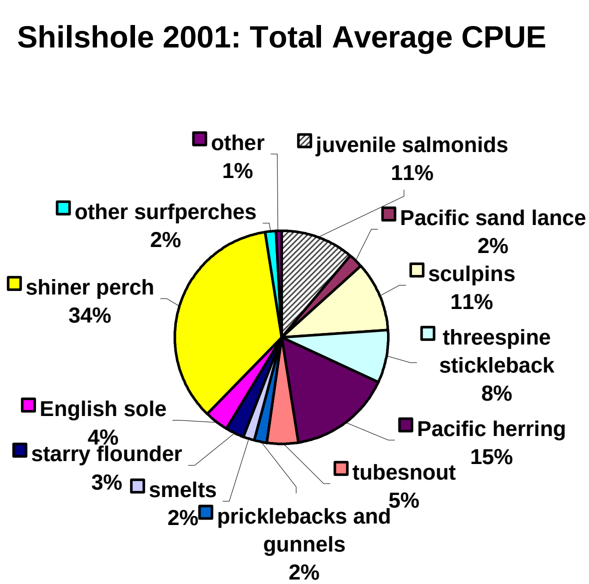

Figure 7 Total catch composition of fishes captured in all beach seine sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001.

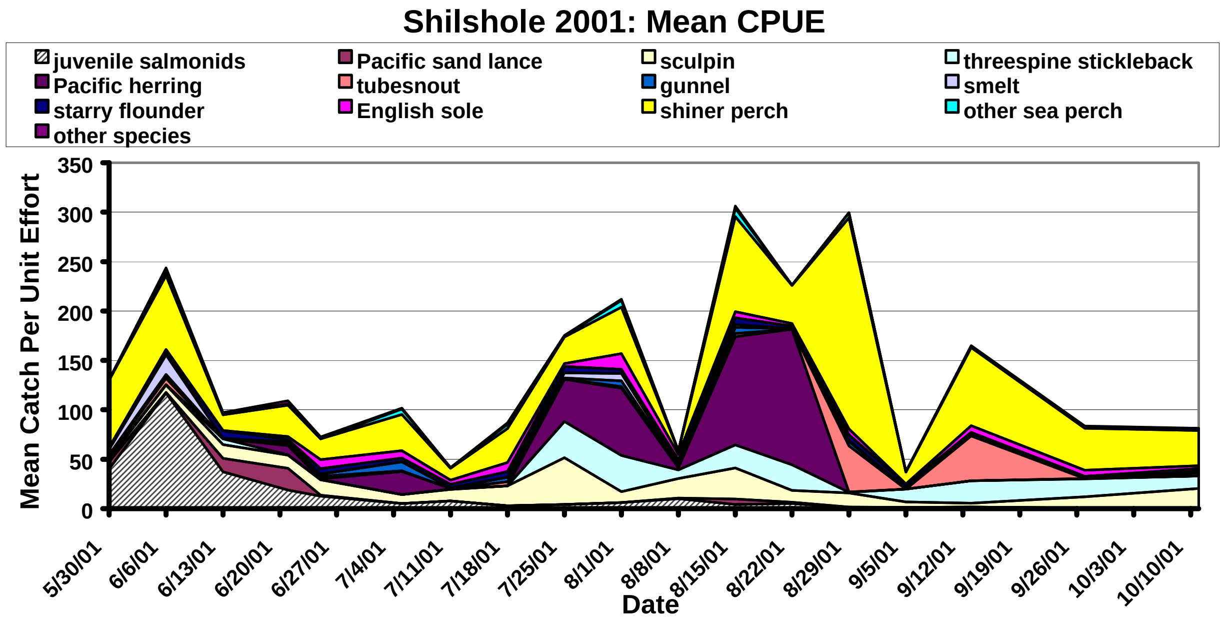

Figure 8 Mean catch per unit of effort (CPUE) of fishes captured in biweekly beach seine sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001.

Sound waters occurred during the salmon outmigration period (0.47 fish m^{-2}) and in July (0.41-0.59 fish m^{-2}). Mean fish densities varied considerably across the sites, with the highest catches (>250 fish per beach seine haul) occurring at the more distant nearshore sites (Breakwater, Golden Gardens, West Point) due to high catches of Pacific herring and shiner perch, intermediate catches in inner Shilshole Bay and two sites on the east shore of the constriction between the mid- and outer Bay, and the lowest catches (~25 fish per beach seine haul) at Statue of Liberty, Boulder and Dolphin 8 (Fig. 9). However, in most cases fish densities were influenced tremendously by the occurrence of high abundances of schooling fishes, such as Pacific herring, shiner perch, Pacific sand lance, and tube-snout. Catches of juvenile salmon tended to be concentrated in the inner- to mid-Shilshole Bay, except for significant densities at Golden Gardens; this later case was due to a single catch of 720 juvenile chum salmon in early June.

The composition of juvenile salmon shifted from being dominated by chum and hatchery chinook salmon from the beginning of sampling until early July, and then relatively constant catches of both unmarked and (adipose fin clipped, hatchery) marked chinook and coho through August (Fig. 10), catches were persistent but low thereafter. Juvenile sockeye (smolts) appeared only sporadically, with a maximum beach seine catch of nine fish at the Dolphin 8 in early June. Except for several exceptions, such as the chum salmon catch noted at Golden Gardens and similarly high catches at West Point and Breakwater in late April, most juvenile salmon catches were concentrated in inner to mid-Shilshole Bay (typically between the Locks and our sampling site at Anthony's (Fig. 11). After June, catches tended to be distributed more evenly around the Bay and adjoining nearshore waters. Disregarding the variable catches in juvenile chum salmon, there was an evident gradient in juvenile salmon density along the estuarine gradient, from beach seine sites immediately below the locks to the outer Bay (Fig. 11). This appeared to be affected most by a trend in decreasing hatchery chinook salmon at increasing distances from the Locks. Wild coho were prominent only in the inner Bay.

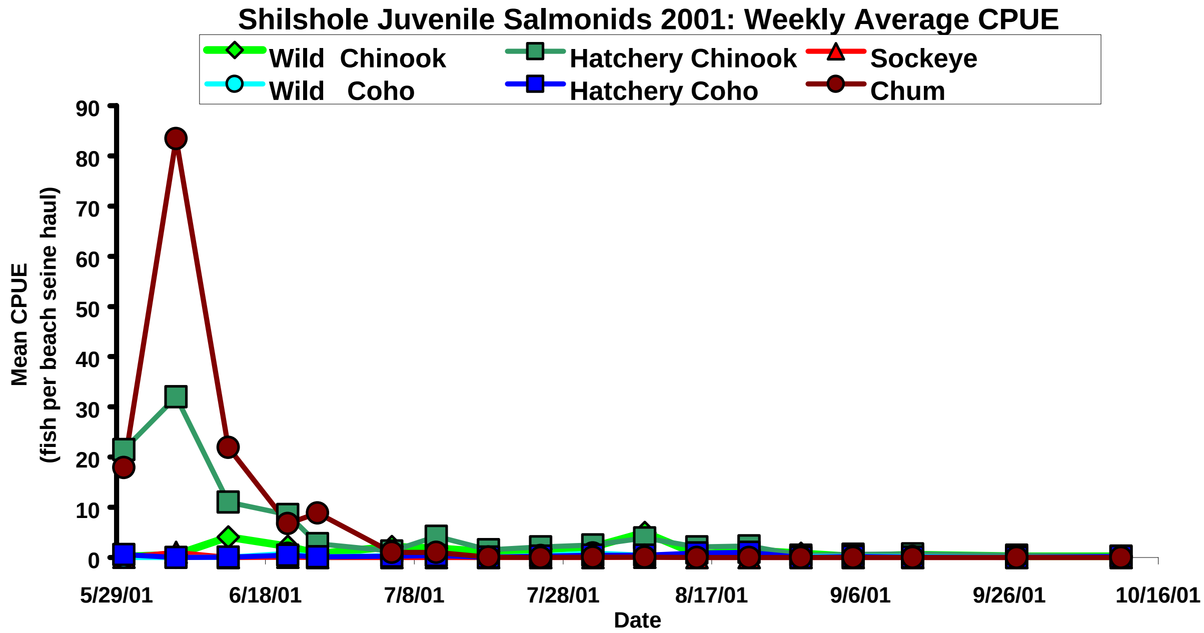

Figure 9 Mean catch per unit of effort (CPUE) of fish taxa captured in biweekly beach seine sampling at eleven sites in Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001.

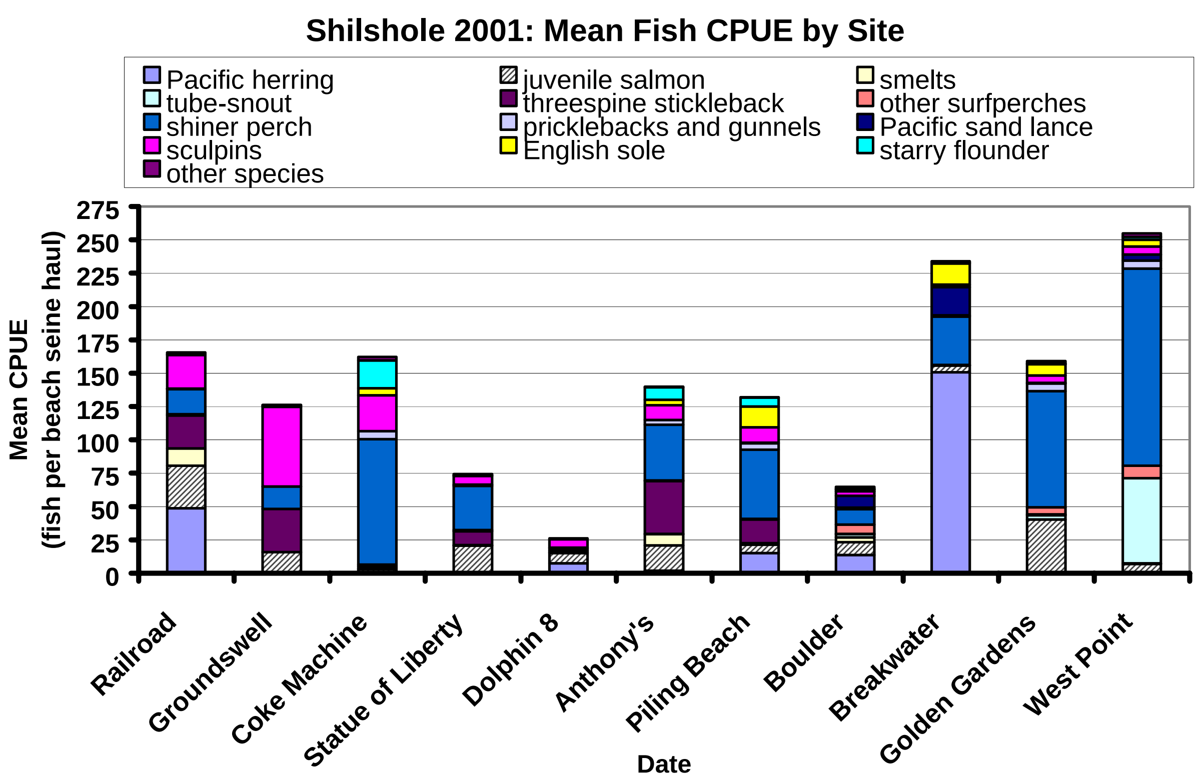

Figure 10 Mean catch per unit of effort (CPUE) of juvenile salmon in biweekly beach seine sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001.

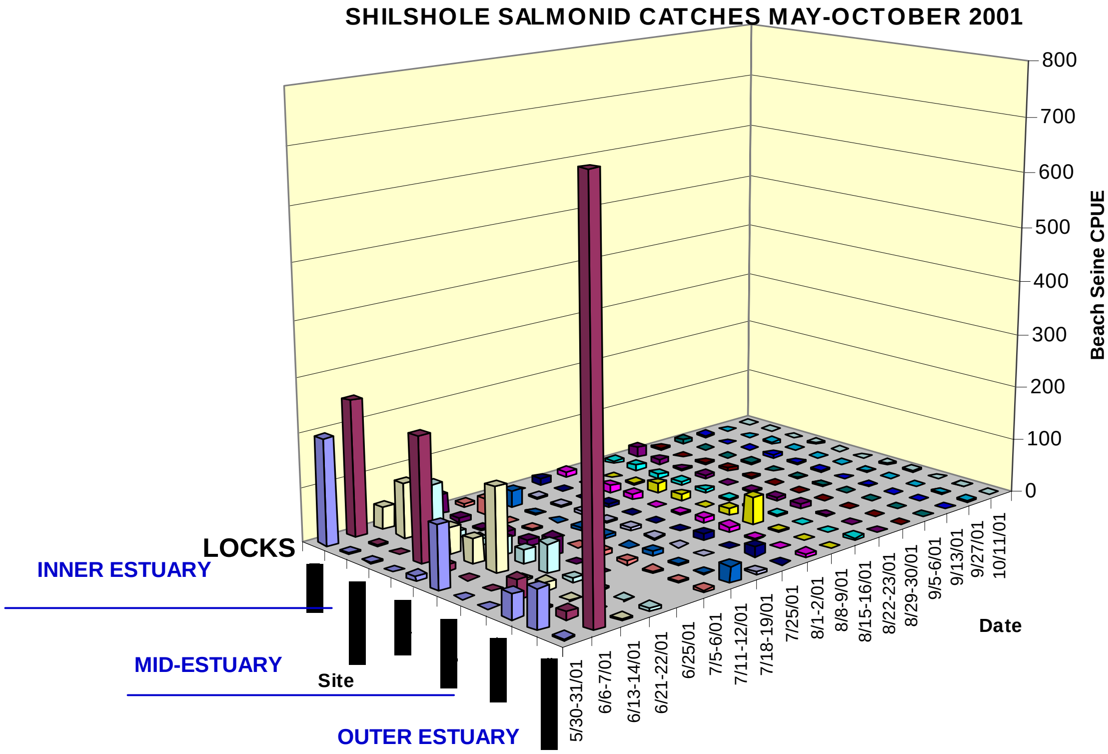

Figure 11 Beach seine catch per unit effort (CPUE) of juvenile salmon at eleven sites in Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001.

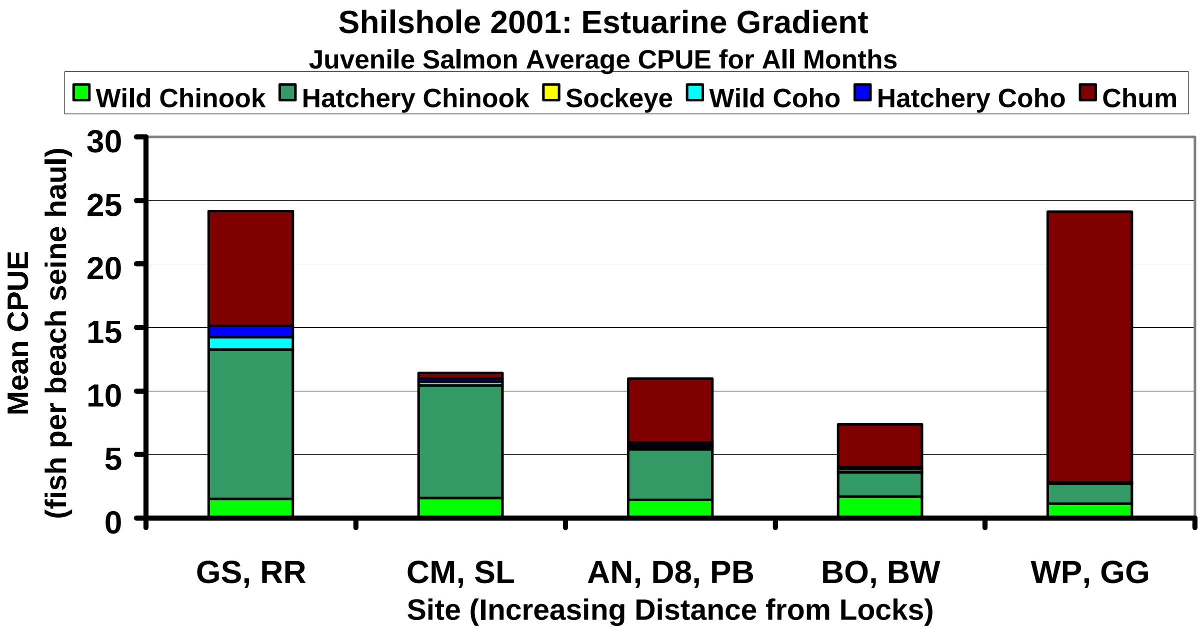

Figure 12 Beach seine catch per unit effort (CPUE) of marked and unmarked juvenile salmon species, according to sites along estuarine gradient, from Locks through Shilshole Bay and adjoining nearshore waters of Puget Sound, 2001. GS, RR = Groundswell and Railroad, SM, SL = Coke Machine and Statue of Liberty, AN, D8, PB = Anthony's, Dolphin 8 and Piling Beach, BO, BW = Boulder and Breakwater in Outer Bay; and WP, GG = West Point and Golden Gardens in adjoining nearshore waters.

Immigration and Residence Time of PIT-Tagged Juvenile Salmon in Shilshole Bay

Despite the intensive effort extended to recapture PIT-tagged juvenile salmon passing through the Locks, the proportion of PIT-tagged fish recaptured during the intensive sampling "blitz" during June 18-22 was relatively low (maximum of 4.4% for chinook) (Fig. 13). To some degree, this is represented by the apparently short residence time of PIT-tagged juvenile chinook at the Shilshole Bay sites (inner and, to a much lesser extent, mid- and outer Bay sites) through the course of the peak migration period during the "blitz" sampling week (Fig. 14). The rapid decline in the ratio of PIT-tagged to untagged chinook, from 0.2 to 0.05, within two days and their disappearance after three days, suggests that the PIT-tagged fish rapidly departed the Bay despite the relatively constant (Railroad site) or no prominent decline in CPUE of juvenile chinook at the same sites. Five PIT-tagged chinook and one coho were recaptured in Shilshole Bay prior to the intensive "blitz" sampling, most of which (4 of the chinook) were caught at just the Statue of Liberty site (DeVries 2002; Table 3-5). All of the recaptured coho were caught within the inner Bay only, three of which originated from the Groundswell site.

Despite the impression that the PIT-tagged chinook recaptured during the "blitz" sampling were rapidly passing through the inner Bay system immediately below the Locks, a large number (69%) of these fish originated from calibration testing of the flumes. The actual residence time of these fish in Shilshole Bay ranged between 1.2 to 31.2 d, but 20 of the fish had apparent estuarine residence times (ignoring the potential of cycling back through the Locks; DeVries

2002) of 13.2-16.6 d. Thus, there is the potential that our sampling reduced a residual population of the PIT-tagged fish in the inner and mid-Bay or that we happened to sample during the period of eventual immigration of fish that were residing ~2 weeks below the Locks.

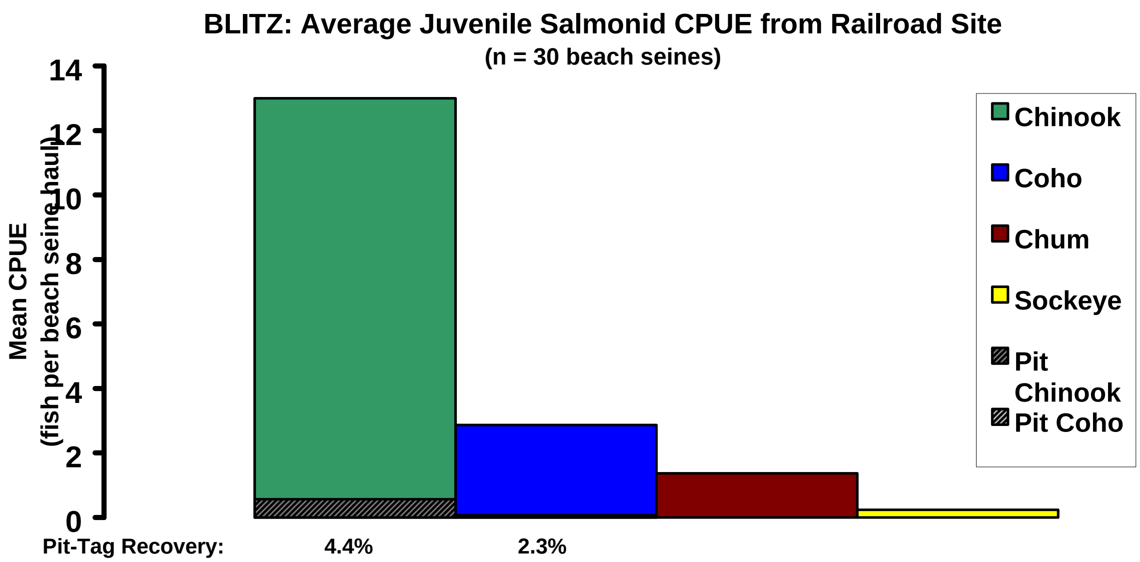

Figure 13 Indication of proportion of PIT-tagged juvenile salmon captured at Railroad (inner Shilshole Bay) site during beach seine sampling blitz during June 18-22, 2001.

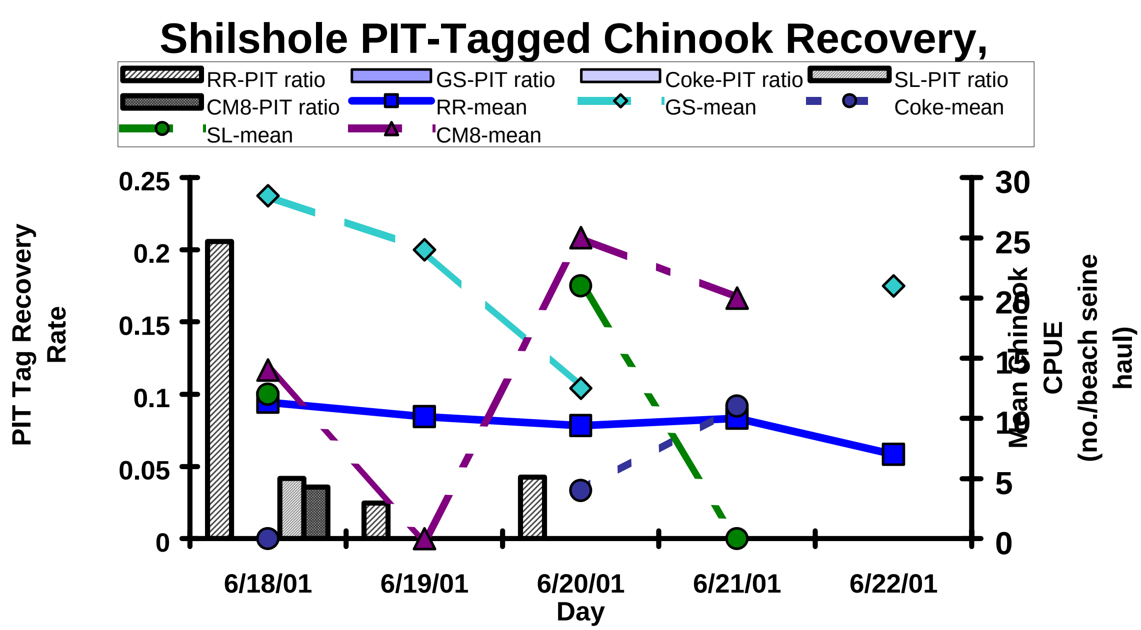

Figure 14 Recovery rate of PIT-tagged individuals and CPUE of juvenile during beach seine sampling blitz during June 18-22, 2001.

DeVries (2002) also noted that 91 chinook and 7 coho were detected twice by the flume detectors, suggesting that recycling back into the Ship Canal through either the small or large lock was not unusual. He also noted that the intervening time between first and second detection shortened as the outmigration season progressed.

Diet Composition of Juvenile Salmon in Shilshole Bay and Adjacent Nearshore Puget Sound Waters

As discovered in preliminary sampling in Shilshole Bay in 1999, we found juvenile salmon in Shilshole Bay and, to some degree, even in the adjoining nearshore waters to be feeding extensively on freshwater zooplankton exported from Lake Washington and the Ship Canal (Figs. 15-20). These allochthonous sources of pelagic organisms, likely entrained in the freshwater surface lens extending into Shilshole Bay from discharge at the Locks, include many prey taxa that are atypical of juvenile salmon in estuaries and nearshore waters of Puget Sound. In many diet composition datasets that we have compiled or are familiar with, epibenthic or benthic and neustonic (surface, drift) organisms tend to be much more prominent in the diet of small juvenile (fry) salmon and pelagic nearshore marine zooplankton are more representative of larger (fingerling-smolt) juveniles. Although represented by the most diverse diet composition of the three species examined, the overall diet composition of juvenile chum salmon captured in Shilshole Bay and adjoining nearshore waters of Puget Sound were dominated (~65-75% total IRI, numerical composition and frequency of occurrence) by the freshwater cladocerans *Daphnia* spp. from Lake Washington and the Ship Canal (Fig. 15); the only other prey taxa of consequence were larvaceans (~30% gravimetric contribution to the diet), which are more

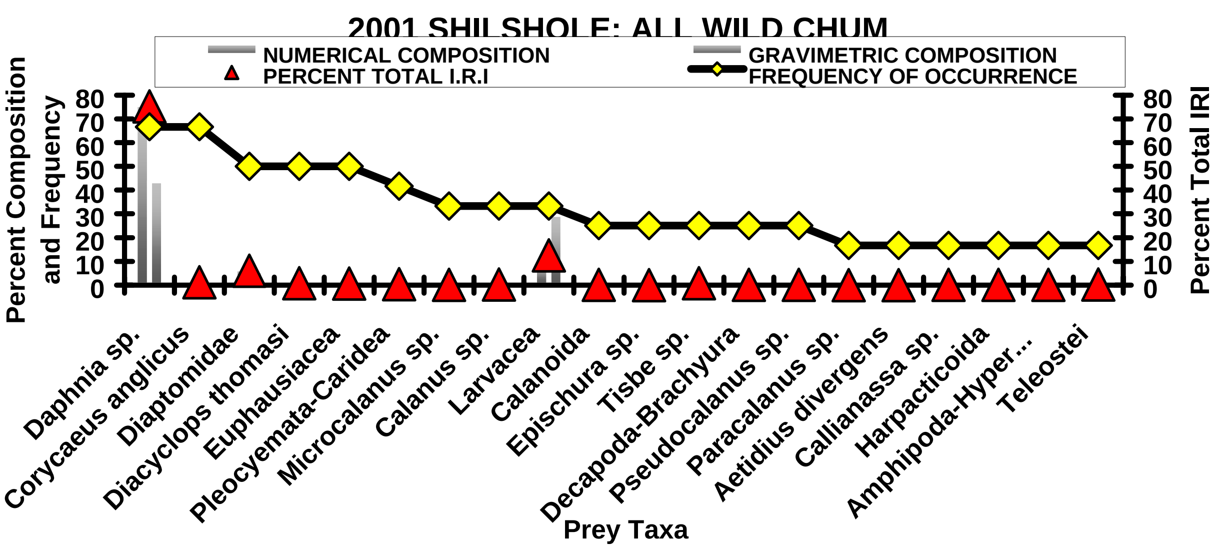

Figure 15 Index of Relative Importance (IRI) diagram of the prey spectrum of all juvenile chum salmon (n = 12; 73.7 ± 12.1 mm FL) captured during sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, April-October 2001; see text for explanation of IRI.

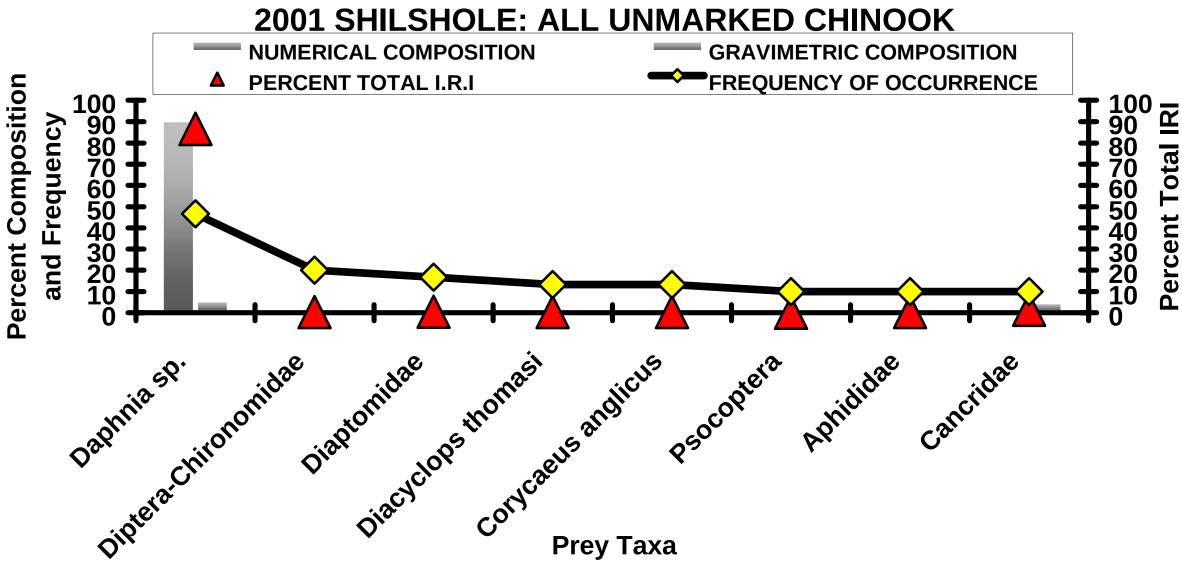

Figure 16 Index of Relative Importance (IRI) diagram of the prey spectrum of all unmarked (wild) juvenile chinook salmon (n = 47; 120.3 ± 30.4 mm FL) captured during sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, April-October 2001; see text for explanation of IRI.

representative of nearshore and marine zooplankton assemblages. Unmarked juvenile chinook had fed almost exclusively on *Daphnia* spp. (Fig. 16), compared to the diet of marked (hatchery) fish, which was dominated more by pelagic larvae of estuarine-nearshore decapods, including Cancridae and Pinnotheridae crabs (Fig. 17); in addition, ~8% of total IRI (representing 9% numerical composition and 23% gravimetric composition) was represented by a few fish that fed extensively upon the polychaete annelid, *Platynereis bicanaliculata*. The four juvenile coho that were examined fed relatively equally (based on IRI) on *Daphnia* spp. and crab larvae, more numerically on the former and gravimetrically on the latter prey, although only two fish had fed on the *Daphnia* spp.

Weekly changes in marked and unmarked juvenile chinook diet composition over their most abundant occurrence in Shilshole Bay, in June and July, indicated no distinct contrasts in the occurrence of prey taxa but a generally larger contribution by insects (larvae and pupae, as well as emergent adult), and epibenthic and benthic prey, in unmarked (wild) chinook, especially in July (Fig. 19). The lower occurrence of marked, hatchery chinook in inner Shilshole Bay may explain this difference, as evidence by the contrast in diet composition of unmarked and marked fish in the inner Bay to the outer Bay (Fig. 20), were both consumed predominantly *Daphnia* spp. in inner Shilshole Bay, but ~20% IRI of the unmarked, wild fish still comprised epibenthic prey and insects, while both hatchery and wild fish in the outer Bay consumed much higher proportions of epibenthic, benthic and insect prey.

Invertebrate Prey Resources in Shilshole Bay

The biweekly sampling of potential prey resources was designed and analyzed to compare potential prey resources of juvenile salmon in inner Shilshole Bay to outer Shilshole Bay. Taxa were classified as to their likely origin and position in the water column, rather than the source of production (e.g., crab larvae are planktonic, even though the reproducing adults are benthic/epibenthic), as well as their known occurrence as prey of juvenile salmon in other estuaries and nearshore environments of Puget Sound.

Zooplankton

As evidenced by the densities of freshwater zooplankton immediately above the Locks (Fig. 21), Lake Washington and the Ship Canal constitute a major allochthonous source of juvenile salmon prey to Shilshole Bay. This assemblage is composed of cladocerans (*Diaphanosoma* sp., *Daphnia* sp. and *Bosmina* sp.), and calanoid (Diaptomidae of different life history stages, *Epischura* sp.) and cyclopoid copepods (*Diacyclops thomasi*). *D. thomasi* occurs in highest density, followed by *Daphnia* sp.and *Bosmina* sp., which occur in relatively similar densities. Due to the introduction of estuarine/marine waters with uplock operations, some nearshore/marine plankton (including principally copepod nauplii, which includes both freshwater and marine taxa) does appear upstream of the Locks, and contributed as much as ~10,000 individuals m^{-3} in early June; other estuarine/nearshore taxa, such as harpacticoid copepods, and freshwater components, such as riparian and aquatic insects usually constituted only a very small proportion. In general, densities of *D. thomasi* declined between early June and late July, while cladocerans and copepods increased or remained constant.

The freshwater plankters were mixed with marine/nearshore plankton and some benthos/epibenthos taxa immediately below the Locks, within inner Shilshole Bay, but still comprised a large proportion of the assemblage (Fig. 22). Overall densities were comparable to above the Locks in early July but had decreased measurably by the next sampling date, from whence the densities and contribution of

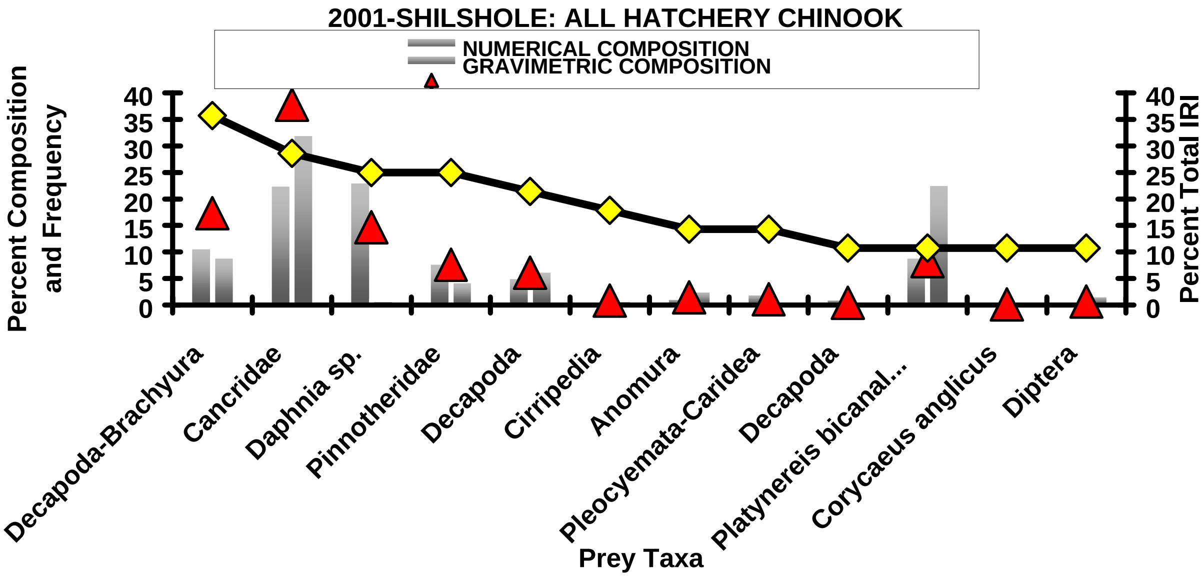

Figure 17 Index of Relative Importance (IRI) diagram of the prey spectrum of all marked (hatchery) juvenile chinook salmon (n = 36; 114.4 ± 17.1 mm FL) captured during sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, April-October 2001; see text for explanation of IRI.

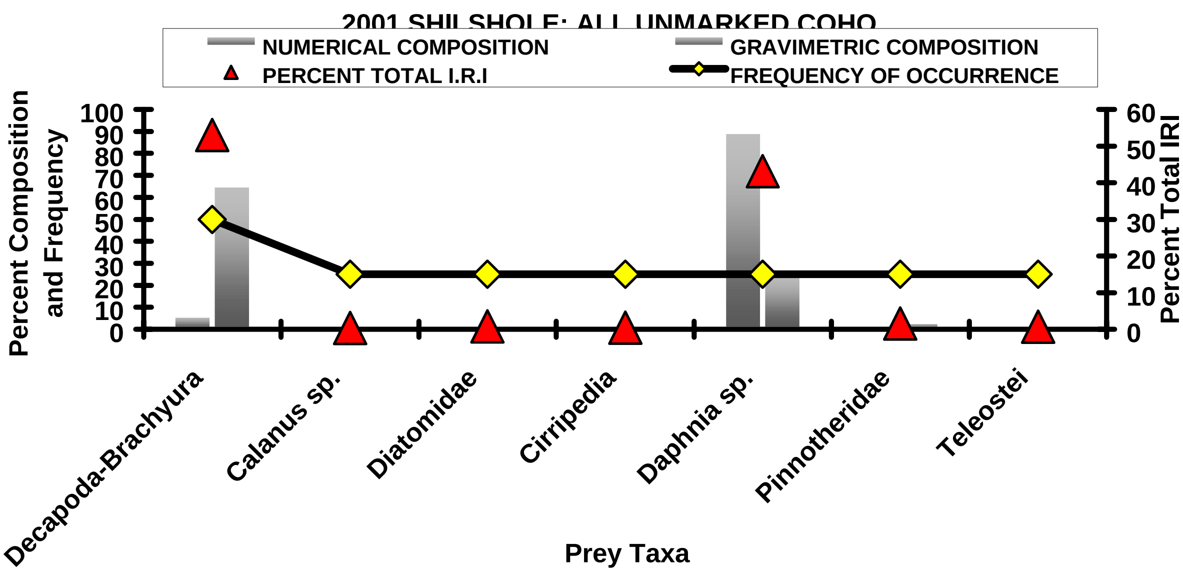

Figure 18 Index of Relative Importance (IRI) diagram of the prey spectrum of all unmarked wild juvenile coho salmon (n = 4; 87.5 ± 8.8 mm FL) captured during sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, April-October 2001; see text for explanation of IRI.

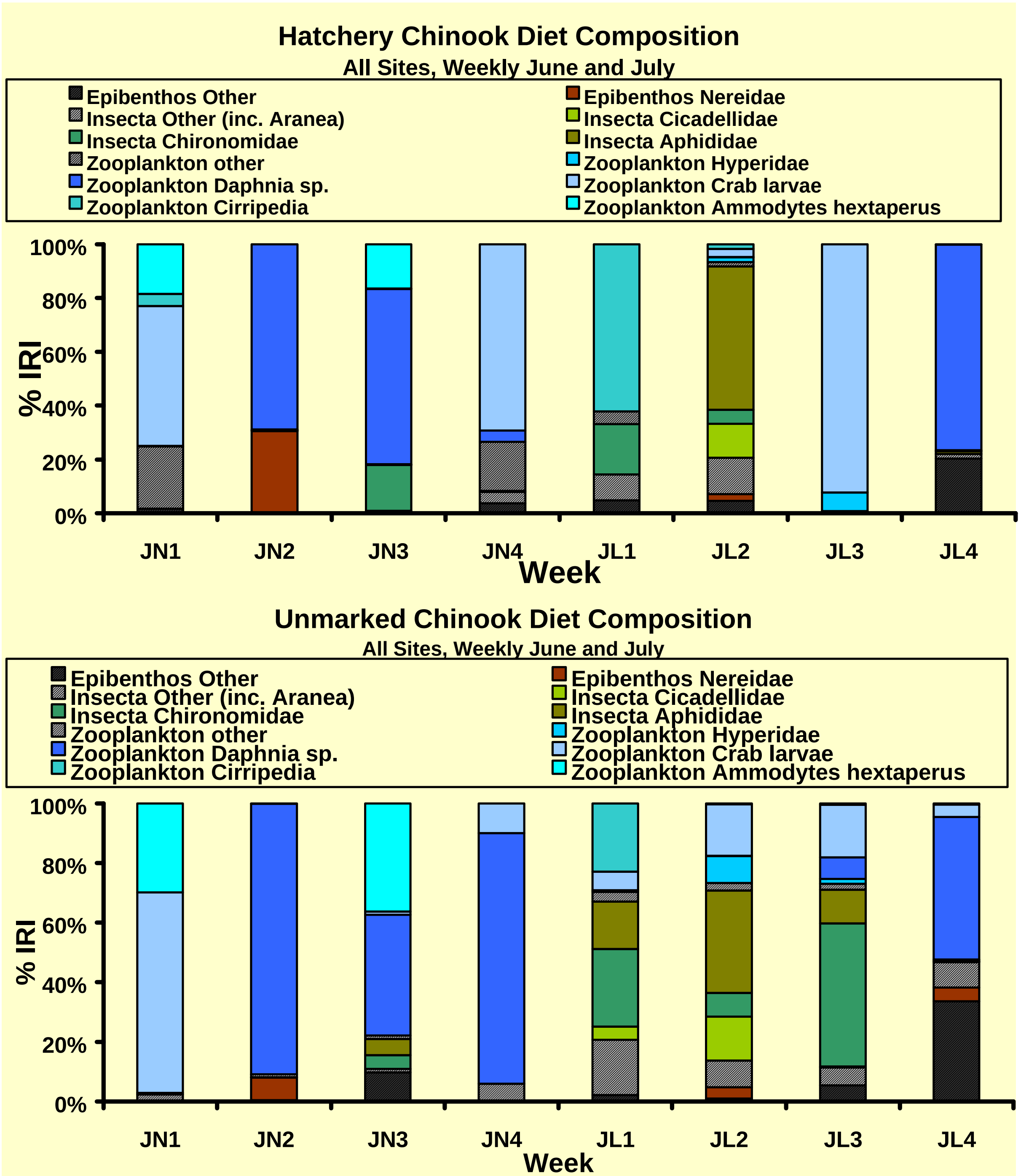

Figure 19 Weekly changes in the Index of Relative Importance (IRI) diet composition of all marked (hatchery) and unmarked (wild) juvenile chinook salmon captured during sampling in Shilshole Bay and adjoining nearshore waters of Puget Sound, April-October 2001; see text for explanation of IRI.

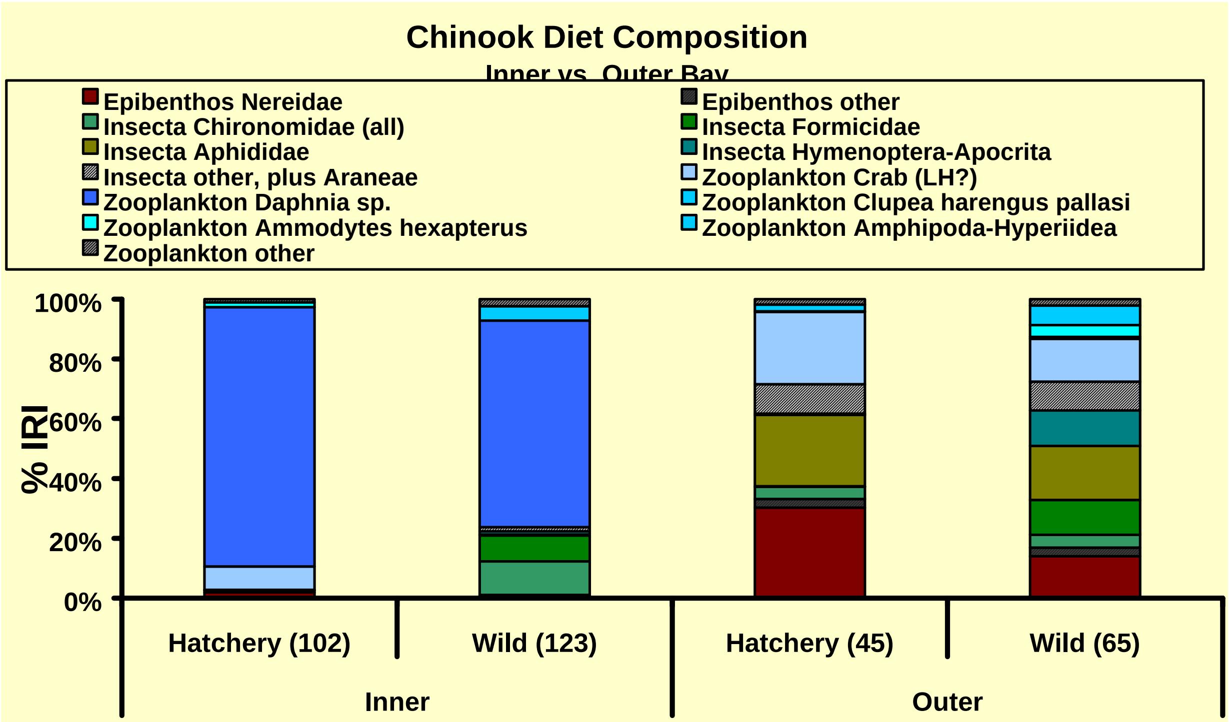

Figure 20 Contrast in Index of Relative Importance (IRI) diet compositions of all marked (hatchery) and unmarked (wild) juvenile chinook salmon captured in inner and outer Shilshole Bay, April-October 2001; see text for explanation of IRI.

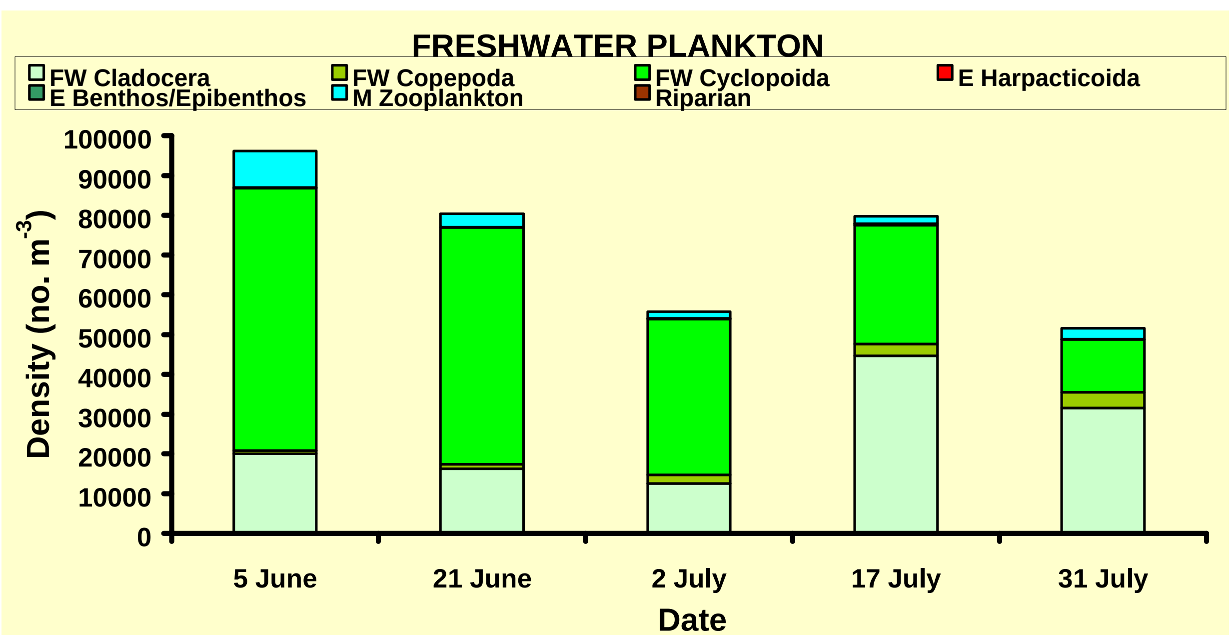

Figure 21 Densities of organisms sampled in vertical plankton net hauls above Locks between 5 June and 31 July 2001; FW = freshwater, E = estuarine/nearshore, and M= nearshore/marine.

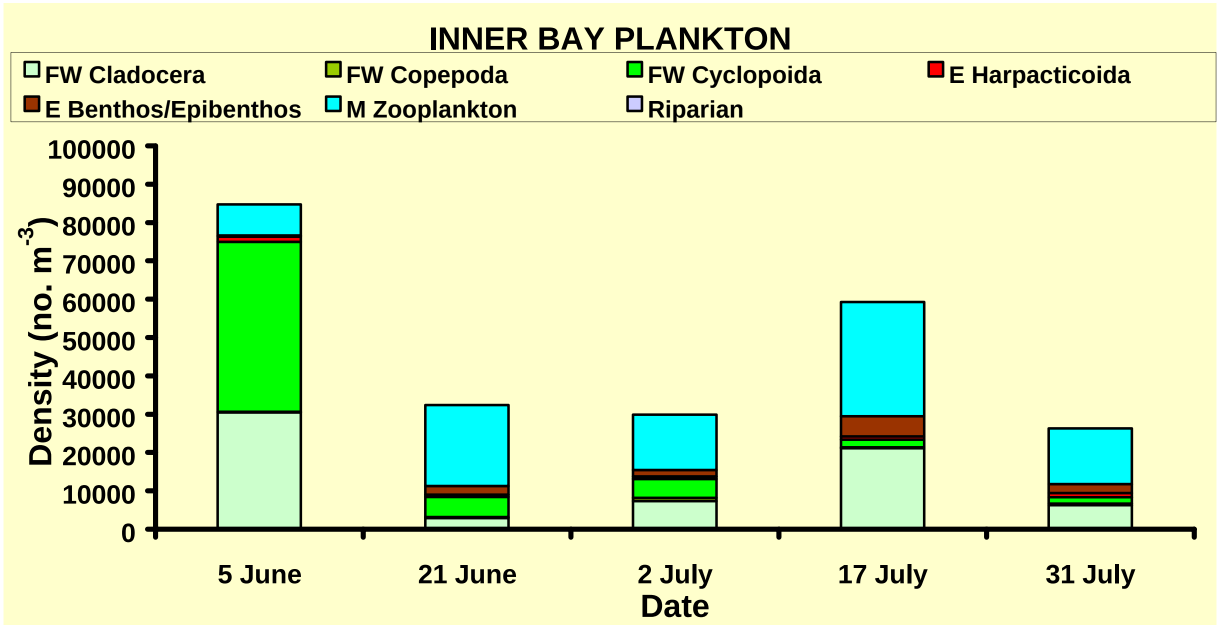

Figure 22 Densities of organisms sampled in vertical plankton net hauls in inner Shilshole Bay between 5 June and 31 July 2001.

freshwater taxa was considerably lower than represented above the Locks. Plankton densities tended to average half that observed above the Locks. Prominent nearshore/marine plankton taxa in this assemblage included the calanoid copepod nauplii and the species *Paracalanus parvus*, the cyclopoid *Corycaeus anglicus* and barnacle nauplii and cyprids. Estuarine/nearshore meroplankton, such as polychaete annelid larvae also appeared prominently in July.

Influence of the freshwater plankton had thoroughly diminished in outer Shilshole Bay and represented a significant proportion of the plankton assemblage only in early June (Fig. 23). D. *thomasi* continued to dominate the residual freshwater portion of the assemblage, and *Daphnia* sp. and *Bosmina* sp. continued to be the more prominent cladocerans, although *Diaphanosoma* sp. had disappeared. Densities were comparable or lower than in the inner Bay. The nearshore/marine constituents were similar to those in the inner Bay, with the addition of several marine taxa, such as copepodids of the calanoid copepod *Calanus* sp. and the larvaceans *Oikopleura* sp.

Epibenthos

The mean density of epibenthic organisms were ~two orders of magnitude more dense in outer Shilshole Bay than in the inner Bay (Fig. 24). While this tended to be due to the dominance of certain taxa, such as nematodes, in the outer Bay sites, other typical epibenthic taxa such as harpacticoids, cumaceans and amphipods illustrated the same contrast in density. Most constituents originated from estuarine/nearshore benthic/epibenthic environments, although some taxa (e.g., calanoid copepod nauplii) could have originated from planktonic populations both above and below the Locks. Of the mean ~ 2.5 x 10^6 m^{-2} densities of epibenthic organisms in the outer Bay, over ~1 x 10^6 m^{-2} were recognized prey of juvenile salmon (based on the Wetland Ecosystem Team database), although prey considered to be "preferred" (e.g., consumed

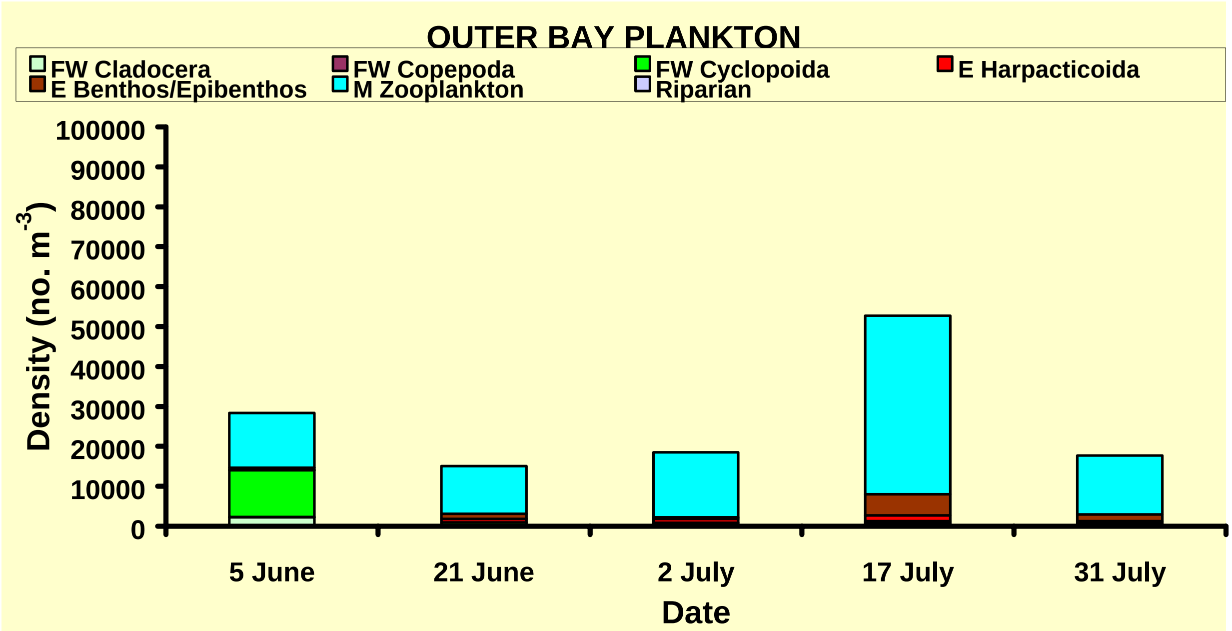

Figure 23 Densities of organisms sampled in vertical plankton net hauls in inner Shilshole Bay between 5 June and 31 July 2001.

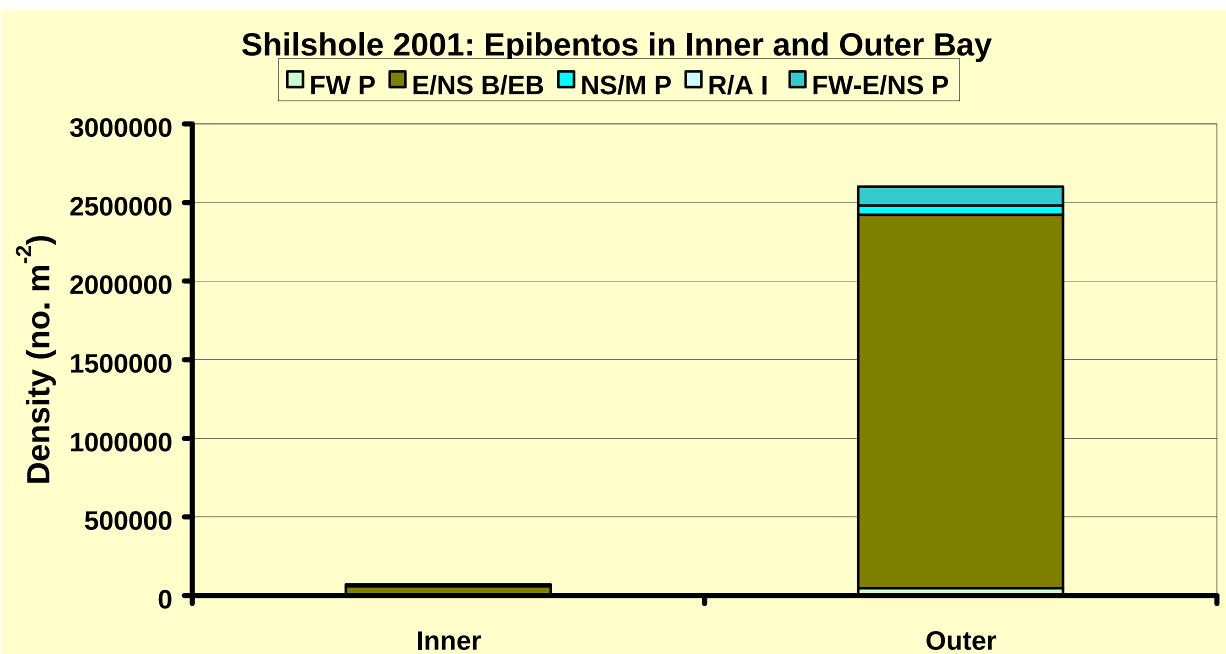

Figure 24 Densities of organisms sampled in epibenthic suction cylinder in inner Shilshole Bay between 5 June and 31 July 2001; FW P = freshwater plankton, E/NS B/EB = estuarine/nearshore benthos/epibenthos, NS/M P = nearshore/marine plankton, R/A I = riparian/aquatic insects, FW-E/NS P = indistinguishable freshwater-estuarine/nearshore plankton.

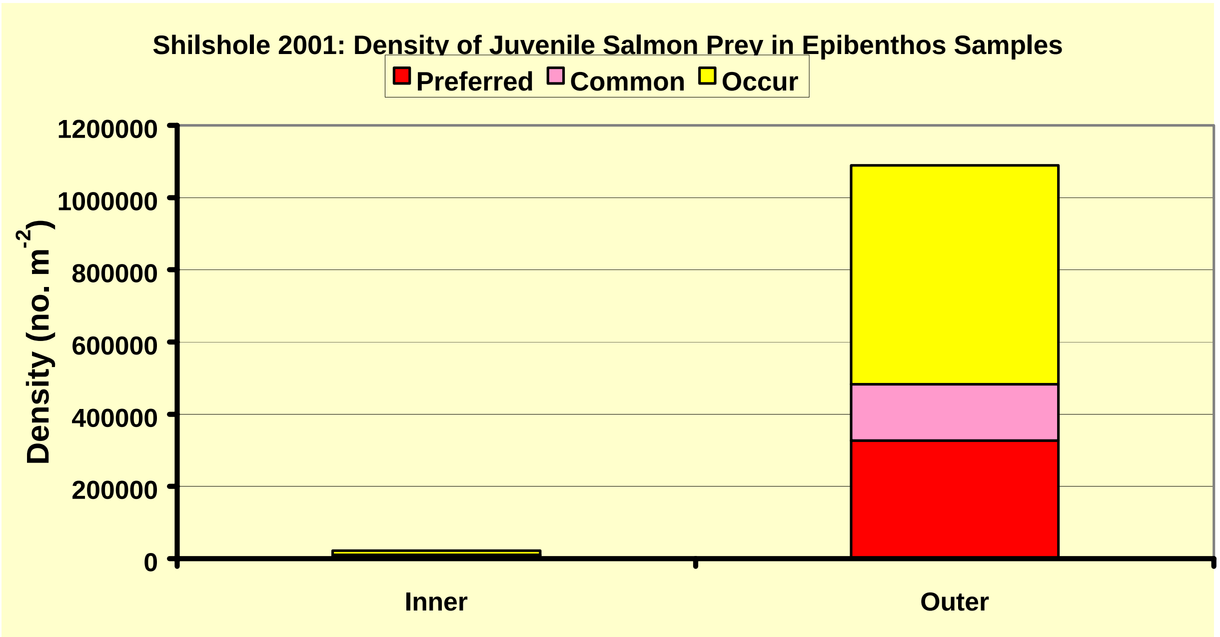

Figure 25 Densities of documented juvenile salmon prey organisms sampled in epibenthic suction cylinder in inner Shilshole Bay between 5 June and 31 July 2001.

prominently) constituted only ~30% of those.

Neuston

Surface neuston, which typically includes both drift insects and several unique taxa of pelagic invertebrates, was completely dominated by freshwater plankton from Lake Washington and the Ship Canal (Figs. 26-27). The neuston taxa composition in inner Shilshole Bay was analogous to the zooplankton assemblage sampled above the Locks, but the pattern of slow decline in plankton density over time was not; rather, after a decline between early and mid-June, densities progressively increased through the remainder of the sampling period. This may reflect the decreased freshwater flow and the increasing concentration of freshwater taxa in an increasingly thinner surface (buoyant freshwater) layer.

Discussion

Results of these investigations of juvenile salmon distribution, relative abundance, diet and prey resource availability below the Locks indicate that:

- juvenile salmon are a prominent component of the fish assemblage occupying Shilshole Bay between April and October;
- juvenile salmon are concentrated in the inner portion of Shilshole Bay, immediately below the Locks, at least through July;
- residence of juvenile chinook salmon may be relatively short, on the order of ~two weeks, and may decrease considerably after late June;

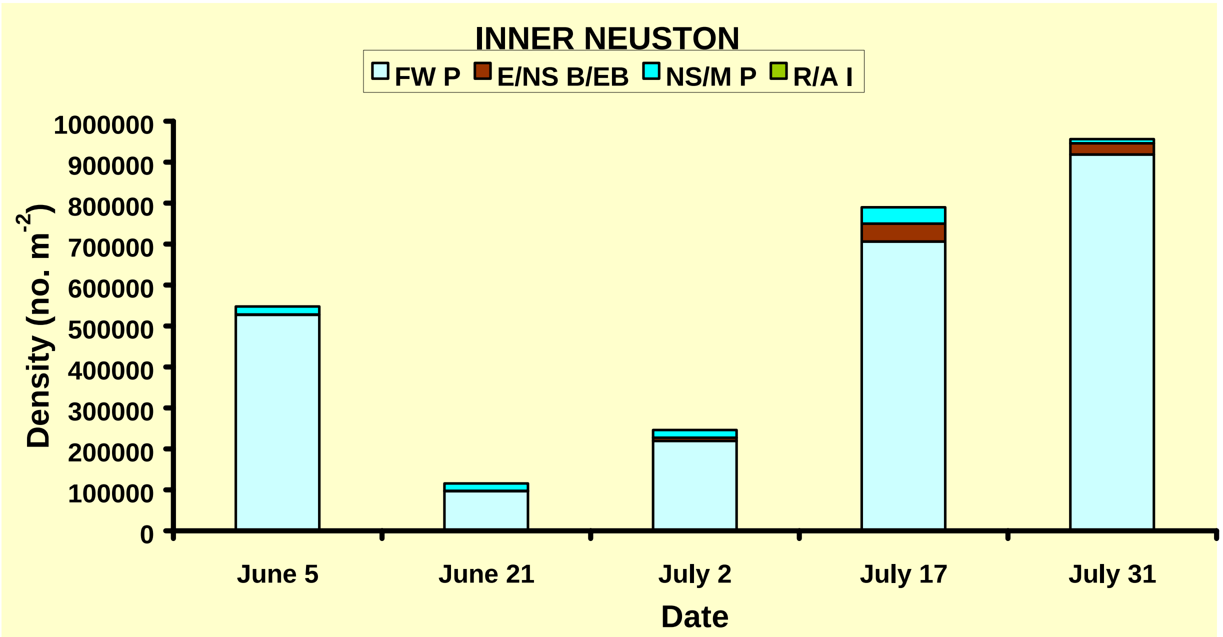

Figure 26 Densities of neustonic (surface/drift) organisms sampled in inner Shilshole Bay between 5 June and 31 July 2001.

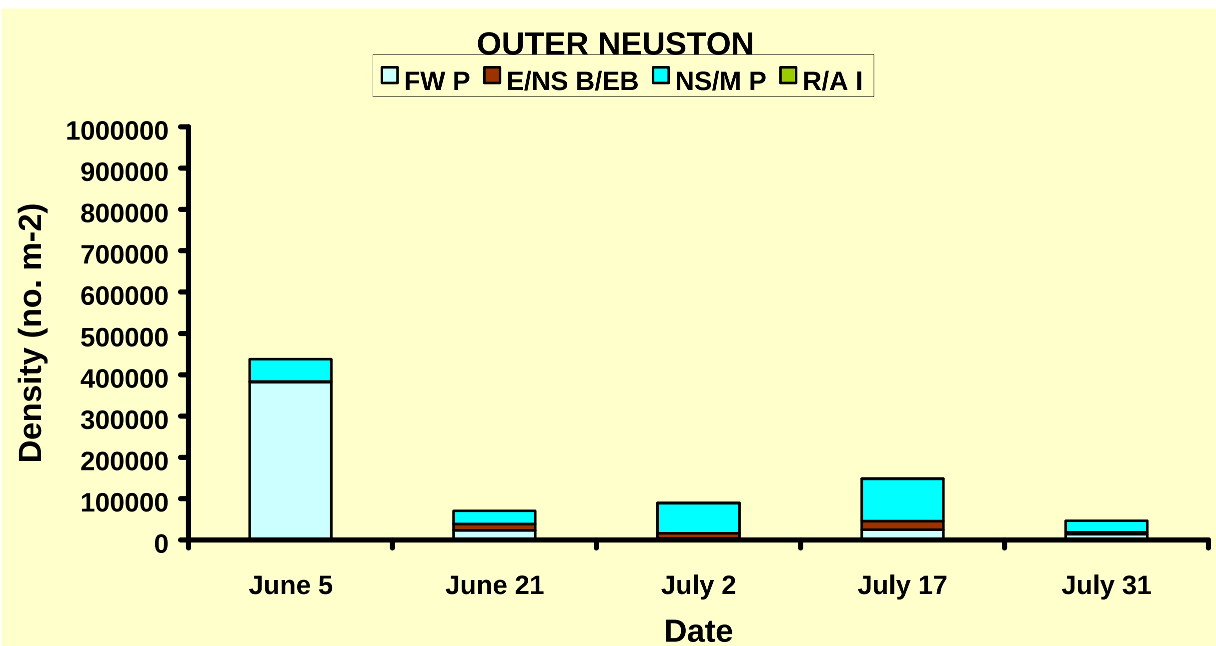

Figure 27 Densities of neustonic (surface/drift) organisms sampled in inner Shilshole Bay between 5 June and 31 July 2001.

- the diet of juvenile salmon within Shilshole Bay is dominated by freshwater zooplankton (especially cladocerans) produced in Lake Washington and the Ship Canal, but in the outer Bay and adjoining nearshore Puget Sound waters crab larvae become more prominent; and,

- zooplankton and neuston invertebrate assemblages below the Locks are dominated by the allochthonous production of freshwater cladocerans and calanoid and cyclopoid copepods, particularly within inner Shilshole Bay, while epibenthic invertebrates, including a high proportion of juvenile salmon prey taxa, are several orders of magnitude more dense in the outer portion of Shilshole Bay.

While the overall composition of nearshore fish community in Shilshole Bay dominated by shiner perch, Pacific herring, Pacific staghorn sculpin, and threespine stickleback, Pacific salmon appeared prominently in May-June and persisted at least through October 2001 (end of sampling). Chum and chinook were the most abundant salmonids. Chum occurred throughout the Bay and adjoining nearshore waters but were particularly abundant nearest Locks and at Golden Gardens. Chinook predominated near the Locks and along northern margin of inner estuary, with hatchery fish predominating nearer Locks compared to outside estuary. The prevalence of chum, which are not produced in the Greater Lake Washington Watershed, and a relatively low percentage of PIT-tagged chinook, in our catches suggests that juvenile salmon from outside those migrating through the Locks are attracted to Shilshole Bay.

Based on PIT tag recoveries, individual juvenile chinook from Lake Washington system appeared to reside for approximately two weeks. The rapid decline in PIT-tagged chinook salmon recoveries during the week of intensive "blitz" sampling, coincident with declining freshwater flow over through the Locks, suggests residence time may also be influenced by the volume of freshwater outflow through the Bay. This was also the period of increasing salinities and decreasing temperatures at 1.5- m and 4-m depth in Shilshole Bay, as measured by the USACE-Seattle District and METRO Kind County (Appendix B). The observed (PIT tag based) residence time is comparatively short for estuarine migration of juvenile chinook, albeit interpreted from limited data. While we have little comparable information from Puget Sound estuaries that are structurally similar to Shilshole Bay, this does conform to the concept that Lake Washington/Lake Sammamish basin chinook are treating (rearing in) the Lake as an estuary and migrating through the "neoestuary" without much further rearing. However, PIT tag data cannot provide real-time behavior information for individual fish. For purposes of understanding Locks outflow and other effects (e.g., Lock recycling) it would be very beneficial to have information on individual fish movement, microhabitat utilization, depth distribution, diel variability, etc.

Unlike other estuarine/nearshore regions of Puget Sound (and elsewhere) feeding by juvenile salmon is supported predominantly by sources from either freshwater production (Lake Washington/Ship Canal) or planktonic, rather than epibenthic/neuston (drift insect). It is unclear whether there is a bioenergetic or ecological "cost" to feeding on these freshwater zooplankton in the Shilshole Bay "neoestuary." Cladocerans such as *Daphnia* sp. may represent a highly efficient prey resource because of lack of avoidance, if stressed by estuarine salinities and temperatures. However, other freshwater cladocerans (i.e., *Bosmina* sp., *Diaphanosoma* sp.) and calanoid (*Diaptomus* sp.) and cyclopoid (*D. thomasi*) copepods are just as or more abundant than *Dapnnia* sp. in the inner Bay's freshwater lens. This implies that the prominence of Daphnia sp. in juvenile salmon diets may reflect more prey selectivity because of the large size and coloration of the *Daphnia* sp.?

The apparent concentration, and potential attraction to other (Puget Sound) juvenile salmonids and fishes to the Bay (and particularly inner Bay) may also be linked to this unique prey resource. However, there is no data to indicate whether this allochthonous prey resource is consumed by the other planktivorous fishes, such as Pacific herring.

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Appendices

A. Zooplankton, epibenthos and neuston classification *(based on Univ. Washington, School of Aquatic and Fishery Sciences' Wetland Ecosystem Team database; J. Cordell and C. Simenstad)*

	PLANKTON	NEUSTON	EPIBENTHOS	
Classification*	**Taxa**	**Taxa**	**Taxa**	**Prey**
E/NS B/EB	Rhizopodea-foraminiferida			
E/NS B/EB			Turbellaria	
E/NS B/EB	Nematoda	Nematoda	Nematoda	
E/NS B/EB	Annelida	Annelida		
E/NS B/EB			Polychaeta	+++
NS/M P	Polychaeta-larva	Polychaeta-larva		
E/NS B/EB	Oligochaeta	Oligochaeta	Oligochaeta	
E/NS B/EB	Gastropoda	Gastropoda	Gastropoda-juv	
NS/M P	Bivalvia-larva	Bivalvia-larva		+
E/NS B/EB			Nudibranchia-juv	
E/NS B/EB			Araneae	++
E/NS B/EB		Acarina		
E/NS B/EB			Halacaridae	
FW P; NS/M P			Cladocera	
FW P	*Diaphanosoma* sp.	*Diaphanosoma* sp.		
FW P	*Daphnia* sp.	*Daphnia* sp.		+++
FW P	*Bosmina* sp.	*Bosmina* sp.		+
NS/M P	*Evadne* sp.			++
NS/M P	*Podon* sp.			++
E/NS B/EB	Ostracoda	*Ostracoda*	Ostracoda	
FW P; NS/M P			Calanoida	
NS/M P	Copepoda-nauplius	Copepoda-nauplius		+
NS/M P		Calanoida-male		
NS/M P	*Calanus* sp.-copepodid	*Calanus* sp.-copepodid		+++
NS/M P		*Calanus* sp.-male		+++
NS/M P		*Calanus* sp.-female		+++
NS/M P	*Calanus pacificus*-copepodid			+++
NS/M P	*Calanus pacificus*-male			+++
NS/M P	*Paracalanus parvus*-copepodid	*Paracalanus parvus*-copepodid		++
NS/M P	*Paracalanus parvus*-male	*Paracalanus parvus*-male		++
NS/M P	*Paracalanus parvus*-female	*Paracalanus parvus*-female		++
NS/M P	*Microcalanus pygmaeus*-copepodid			+
NS/M P	*Microcalanus pygmaeus*-female			+
NS/M P	*Microcalanus* sp.-copepodid			+
NS/M P	*Microcalanus* sp.-male			+
NS/M P	*Microcalanus* sp.-female			+
NS/M P	*Pseudocalanus* sp.-copepodid	*Pseudocalanus* sp.-copepodid		+++
NS/M P	*Pseudocalanus* sp.-male	*Pseudocalanus* sp.-male		+++
NS/M P	*Pseudocalanus* sp.-female	*Pseudocalanus* sp.-female		+++
NS/M P	*Metridia lucens*-female			+++

NS/M P	*Metridia lucens*-copepodid			+++
NS/M P	*Centropages abdominalis*-copepodid			+
NS/M P	*Centropages abdominalis*-male			+
NS/M P	*Aetidius armatus*-copepodid			+
NS/M P	*Aetidius armatus*-male			+
NS/M P	*Aetidius armatus*-female			+
NS/M P	*Stephos* sp.-copepodid	*Stephos* spp.-copepodid		
NS/M P	*Stephos* sp.-female			
NS/M P	*Stephos pacificus*-male			
NS/M P	*Stephos pacificus*-female			
FW P	Diaptomidae-copepodid	Diaptomidae-copepodid		+
FW P	Diaptomidae-male	Diaptomidae-male		+
FW P	Diaptomidae-female	Diaptomidae-female		+
FW P	*Epischura* sp.-copepodid			++
NS/M P	*Acartia longiremis*-copepodid	*Acartia longiremis*-copepodid		++
NS/M P	*Acartia longiremis*-male	*Acartia longiremis*-male		++
NS/M P	*Acartia longiremis*-female			++
NS/M P	*Acartia* (*Acartiura*) spp.-female			++
NS/M P	*Tortanus discaudatus*-copepodid			+
NS/M P	*Tortanus discaudatus*-male			+
E/NS B/EB	Harpacticoida	Harpacticoida	Harpacticoida	
E/NS B/EB	Harpacticoida-copepodid	Harpacticoida-copepodid	Harpacticoida-copepidid	
E/NS B/EB	Harpacticoida-male	Harpacticoida-male		
E/NS B/EB	Harpacticoida-female	Harpacticoida-female		
E/NS B/EB			*Longipedia* sp.	+
E/NS B/EB			Ectinosomatidae	+
E/NS B/EB			*Harpacticus* sp.	
E/NS B/EB			*Harpacticus* sp.-copepodid	
E/NS B/EB			*Harpacticus uniremis*	+++
E/NS B/EB			*Harpacticus spinulosus*	+
E/NS B/EB			*Harpacticus spinulosus*-copepodid	+
E/NS B/EB			*Harpacticus spinulosus*-mating pair	+
E/NS B/EB			*Harpacticus* sp.-obscurus group	++
E/NS B/EB			*Zaus* sp.	++
E/NS B/EB			*Zaus* sp.-copepodid	++
E/NS B/EB			*Tisbe* sp.	+++
E/NS B/EB			*Tisbe* sp.-copepodid	+++
E/NS B/EB			*Scutellidium* sp.	++
E/NS B/EB			*Microarthridion littorale*	+
E/NS B/EB			*Microarthridion littorale*-copepodid	+
E/NS B/EB			*Tachidius triangularis*	++
E/NS B/EB			*Danielssenia typica*	
E/NS B/EB			Laophontidae-copepodid	
E/NS B/EB			Paralaophonte sp.	
E/NS B/EB			*Paralaophonte pacifica*	
E/NS B/EB			*Paralaophonte perplexa* gr.	
E/NS B/EB			*Laophonte cornuta*	
E/NS B/EB			*Normanella* sp.	
E/NS B/EB			*Pseudonychocamptus* sp.	
E/NS B/EB			*Heterolaophonte* sp.	

E/NS B/EB			*Heterolaophonte discophora*	+
E/NS B/EB			*Heterolaophonte discophora*-copepodid	+
E/NS B/EB			*Heterolaophonte longisetigera*	+
E/NS B/EB			*Heterolaophonte longisetigera*-copepodid	+
E/NS B/EB			*Heterolaophonte virabilis*	
E/NS B/EB			Laophontidae-unidentified	
E/NS B/EB			Ameiridae	
E/NS B/EB			*Nitocra* sp.	
E/NS B/EB			*Ameira* sp.	+
E/NS B/EB			*Ameira* sp.-copepodid	+
E/NS B/EB			*Enhydrosoma* sp.	
E/NS B/EB			*Huntemannia jadensis*	++
E/NS B/EB			*Leimia vaga*	++
E/NS B/EB			*Leimia vaga*-copepodid	++
E/NS B/EB			*Acrenhydrosoma* sp.	
E/NS B/EB			*Stylicletodes* sp.	
E/NS B/EB			Diosaccidae	
E/NS B/EB			Diosaccidae-copepodid	
E/NS B/EB			*Amonardia* sp.-copepodid	
E/NS B/EB			*Amonardia perturbata*	++
E/NS B/EB			*Diosaccus spinatus*	
E/NS B/EB			*Diosaccus spinatus*-copepodid	
E/NS B/EB			*Amphiascopsis cinctus*	++
E/NS B/EB			*Amphiascus* spp.	
E/NS B/EB			*Amphiascus* spp.-copepodid	
E/NS B/EB			*Schizopera* sp.	
E/NS B/EB			*Stenhelia* sp.	
E/NS B/EB			*Stenhelia peniculata*	++
E/NS B/EB			*Typhlamphiascus* sp.	
E/NS B/EB			*Amphiascoides* sp. a	
E/NS B/EB			*Robertsonia* sp.	
E/NS B/EB			*Mesochra* sp.	
E/NS B/EB			*Mesochra* pygmaea	++
E/NS B/EB			*Orthopsyllus illgi*	
E/NS B/EB			*Paradactylopodia* sp.	
E/NS B/EB			*Parathalestris* sp.	
E/NS B/EB			*Parathalestris californica*	
E/NS B/EB			*Diarthrodes* sp.	
E/NS B/EB			*Thalestris* sp.	
E/NS B/EB			*Rhyncothalestris helgolandica*	
E/NS B/EB			*Dactylopusia* sp.	++
E/NS B/EB			*Dactylopusia* sp.-copepodid	++
E/NS B/EB			*Dactylopusia vulgaris*	++
E/NS B/EB			*Dactylopusia crassipes*	+++
E/NS B/EB			*Parastenhelia* sp.	+
E/NS B/EB			*Parastenhelia hornelli*	+
E/NS B/EB			*Parastenhelia spinosa*	+
FW P; NS/M P			Cyclopoida	+
NS/M P	*Oncaea* sp.-copepodid	*Oncaea* sp.-copepodid		+
NS/M P	*Oncaea* sp.-male	*Oncaea* sp.-male		+
NS/M P	*Oncaea* sp.-female	*Oncaea* sp.-female		+

NS/M P			*Corycaeus anglicus*	++
NS/M P	*Corycaeus anglicus*-copepodid	*Corycaeus anglicus*-copepodid		++
NS/M P	*Corycaeus anglicus*-male	*Corycaeus anglicus*-male		++
NS/M P	*Corycaeus anglicus*-female	*Corycaeus anglicus*-female		++
NS/M P			Cyclopinidae	+
NS/M P		*Hemicyclops* sp.	*Hemicyclops* sp.	
NS/M P	*Hemicyclops* sp.-copepodid		*Hemicyclops* sp.-copepodid	
FW P			*Diacyclops thomasi*	+
FW P	*Diacyclops thomasi*-copepodid	*Diacyclops thomasi*-copepodid		+
FW P		*Diacyclops thomasi*-juv		+
FW P	*Diacyclops thomasi*-male	*Diacyclops thomasi*-male		+
FW P	*Diacyclops thomasi*-female	*Diacyclops thomasi*-female		+
NS/M P	*Oithona similis*-copepodid	*Oithona similis*-copepodid		+
NS/M P	*Oithona similis*-male	*Oithona similis*-male		+
NS/M P	*Oithona similis*-female	*Oithona similis*-female		+
NS/M P			Caligoida	+
E/NS B/EB		Cirripedia		
NS/M P	Cirripedia-nauplius	Cirripedia-naulpius	Cirripedia-nauplius	++
NS/M P			Cirripedia-juv	++
NS/M P		Cirripedia-exuviae	Cirripedia-exuviae	++
NS/M P	Cirripedia-cypris	Cirripedia-cypris	Cirripedia-cypris	+
E/NS B/EB	Cumacea		Mysidacea-juv	
E/NS B/EB				
E/NS B/EB			*Lamprops quadriplicata*	++
E/NS B/EB			*Nippoleucon* sp.	++
E/NS B/EB			*Diastylopsis tenuis*	++
E/NS B/EB			*Cumella vulgaris*	+++
E/NS B/EB			*Leptochelia dubia-juv*	++
E/NS B/EB			*Leptochelia dubia*	++
E/NS B/EB			Isopoda	
E/NS B/EB			*Gnorimosphaeroma oregonensis*	++
E/NS B/EB			*Munna* sp.-juv	
E/NS B/EB			Bopyridae	+
E/NS B/EB	Epicaridea-juv			+
E/NS B/EB	Amphipoda-juv+adult	Amphipoda		
E/NS B/EB		Gammaridea-juv	Gammaridea-juv	++
E/NS B/EB			*Americhelidium* sp.-juv	+
E/NS B/EB			Ampithodae-juv	+
E/NS B/EB			*Ampithoe* sp.-juv	+
E/NS B/EB			Calliopiidae	+++
E/NS B/EB			*Paracalliopiella pratti*	+++
E/NS B/EB		*Corophium* sp.	*Corophium* sp.	+++
E/NS B/EB			*Corophium* sp.-juv	+++
E/NS B/EB			*Pontogeneia* sp. cf *rostrata*-juv	++
E/NS B/EB			*Pontogeneia* sp. cf *rostrata*	++
E/NS B/EB			*Anisogammarus pugettensis*-juv	+++
E/NS B/EB			*Eogammarus* sp.-juv	+++
E/NS B/EB			*Eogammarus* sp.	+++
E/NS B/EB			Anisogammaridae-juv	+++
E/NS B/EB			*Hyale* sp.-juv	
E/NS B/EB			*Photis* sp.-juv	+
E/NS B/EB			*Gammaropsis* sp.	
E/NS B/EB				
E/NS B/EB				

NS/M P	Hyperiidae	Hyperiidae		++
NS/M P	*Parathemisto* sp.-juv+adult	*Parathemisto* sp.-juv		++
NS/M P	*Hyperia sp*-adult			
E/NS B/EB		Caprellidea		
E/NS B/EB			Caprellidae-juv	
NS/M P	Euphausiidae-juv			+++
NS/M P	Euphausiidae-larvae	Euphausiidae-larvae		+++
NS/M P	Euphausiidae-male	Euphausiidae-male		+++
NS/M P		Euphausiidae-female		+++
E/NS B/EB		Decapoda-brachyura		+++
E/NS B/EB			Hippolytidae	++
E/NS B/EB	Hippolytidae-juv+adult	Hippolytidae-juv	Hippolytidae-juv	++
E/NS B/EB	Hippolytidae-larva			++
E/NS B/EB			Heptacarpus sitchensis-juv	
E/NS B/EB	Pandalidae-juv	Pandalidae-juv		
NS/M P	Crangonidae-larva			++
E/NS B/EB	*Crangon* sp.			
E/NS B/EB	*Crangon* sp.-juv			+
E/NS B/EB			Callianassidae-juv	+
NS/M P			*Neotrypaea* sp.-larva	++
E/NS B/EB			Paguridae-juv	+
E/NS B/EB	Xanthidae			
NS/M P	Xanthidae-zoea	Xanthidae-zoea		++
E/NS B/EB	Xanthidae-megalop			++
NS/M P		Majidae-zoea		+
NS/M P	Pinnotheridae-zoea		Porcellanidae-zoea	++
NS/M P			Pinnotheridae-zoea	++
E/NS B/EB			Pinnotheridae-juv	++
NS/M P	Grapsidae-zoea		Grapsidae-zoea	+
R/A I		Thysanoptera-adult		+
R/A I		Plecoptera-nymph		+
		Ephemeroptera-nymph		+
			Trichoptera-larva	+
R/A I		Aphidoidea-juv+adult		++
		Psyllidae-adult		++
		Cicadellidae-nymph+adult		++
		Delphacidae-nymph+adult		+
R/A I		Isotomidae		++
R/A I		Hempitera-nymph		++
		Miridae-adult		+
		Saldidae-nymph+adult		+
		Tingidae-adult		+
		Lygaeidae-adult		+
R/A I		Collembola		+++
			Coleoptera-larva	+
R/A I	Coleoptera-adult	Coleoptera-adult		++
		Staphylinidae-adult		++
		Coccinellidae-adult		+
R/A I			Diptera Chironomidae	+++
R/A I		Diptera/Chironomidae	Diptera Chironomidae-larva	+++
R/A I		Diptera/Chironomidae-larva		+++
R/A I		Diptera/Chironomidae-pupa		+++
		Cecidomyiidae-adult		++
		Ceratopogonidae-adult	Ceratopogonidae-larva	++

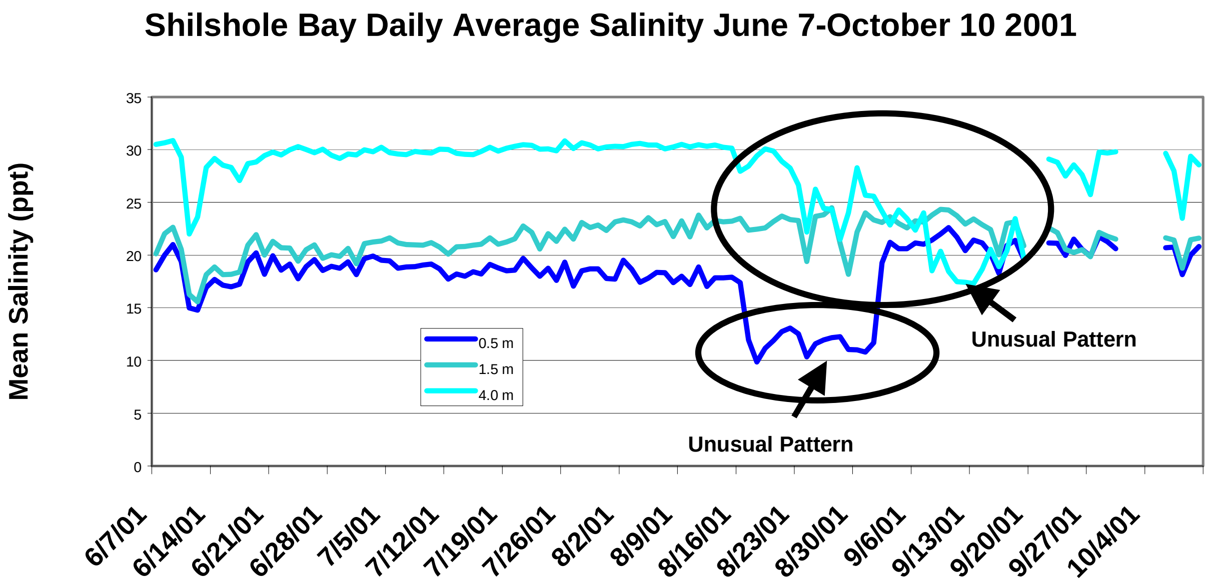
			Simuliidae-larva	+
		Sphaeroceridae-adult		+
		Psychodidae-adult		+
		Muscidae-adult		+
		Mycetophilidae-adult		+
		Phoridae-adult		+
		Chloropidae-adult		+
		Tipulidae-adult		++
R/A I		Ephydridae-pupa+adult		++
R/A I		Dolichopodidae-adult		++
R/A I		Psocoptera-adult		++
		Sciaridae-adult		++
R/A I		Formicidae-adult		++
R/A I		Ichneumonoidea-adult		+
R/A I		Chalcoidea-adult		+
NS/M P	*Sagitta* spp.	*Sagitta* sp.		++
NS/M P	*Oikopleura* sp.	*Oikopleura* sp.		+++
NS/M P		Teleosti-larva		+++

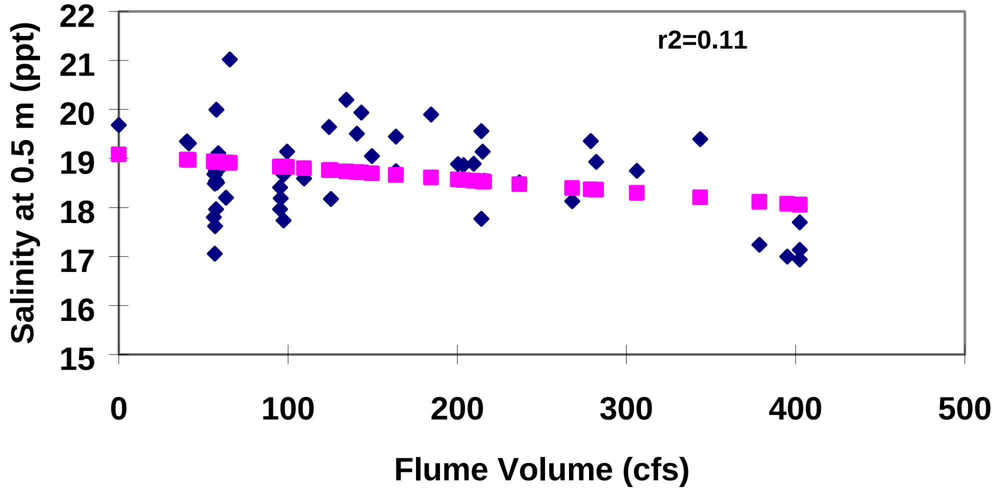
* classes

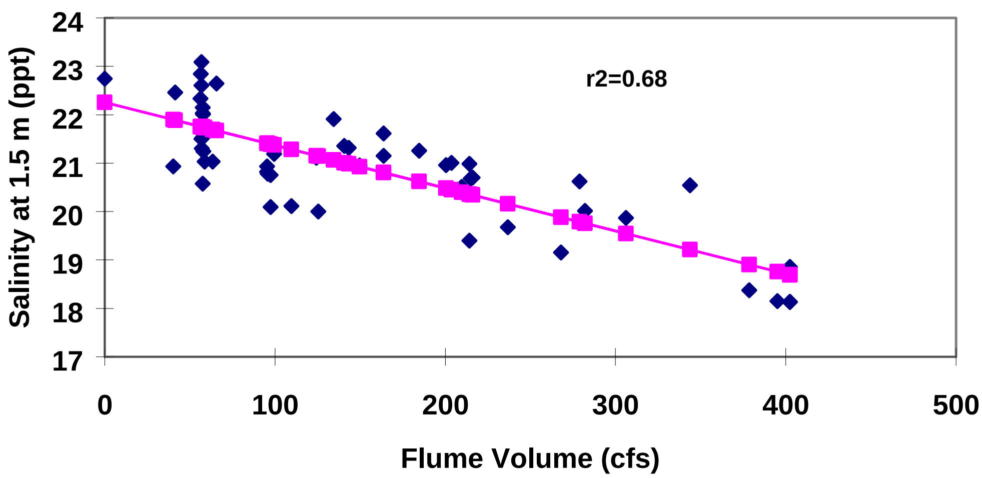
FW P = freshwater planktonic
E/NS B/EB = estuarine/nearshore benthic/epibenthic
NS/M P = marine planktonic
R/A I = riparian/aquatic insects

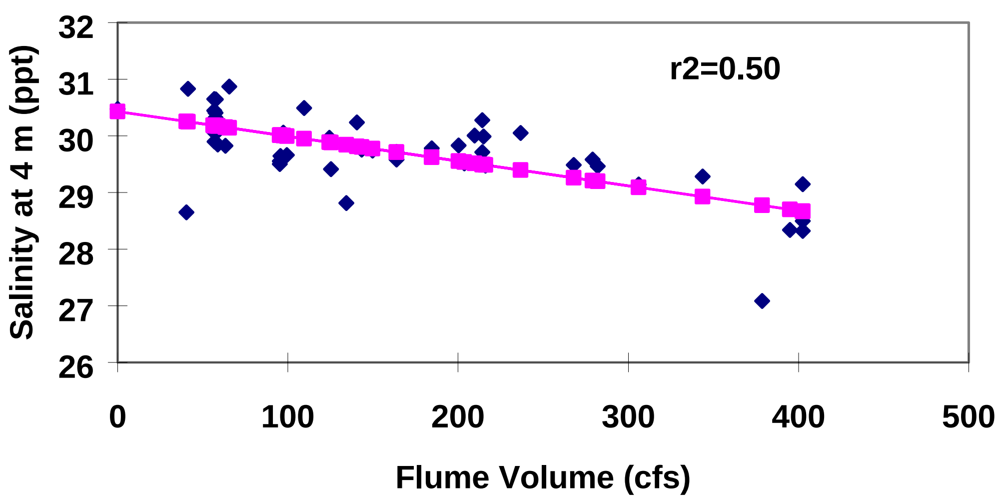
** prey
+++= prominent
++ = occurs commonly
+ = occurs rarely

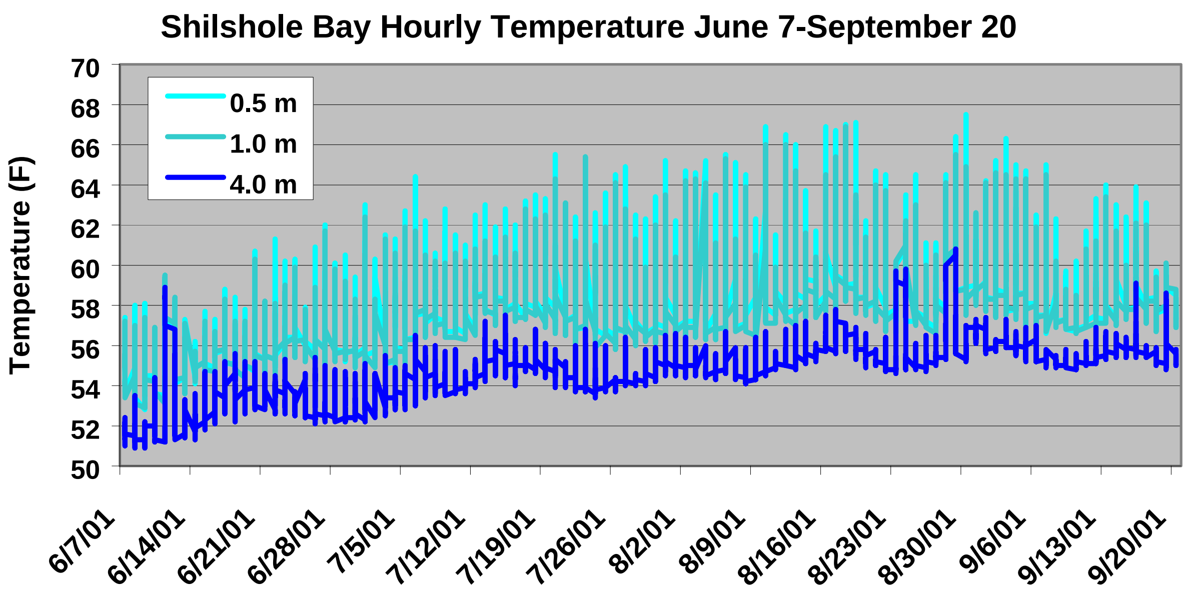
B. USACE-Seattle District and METRO King County salinity-temperature plots

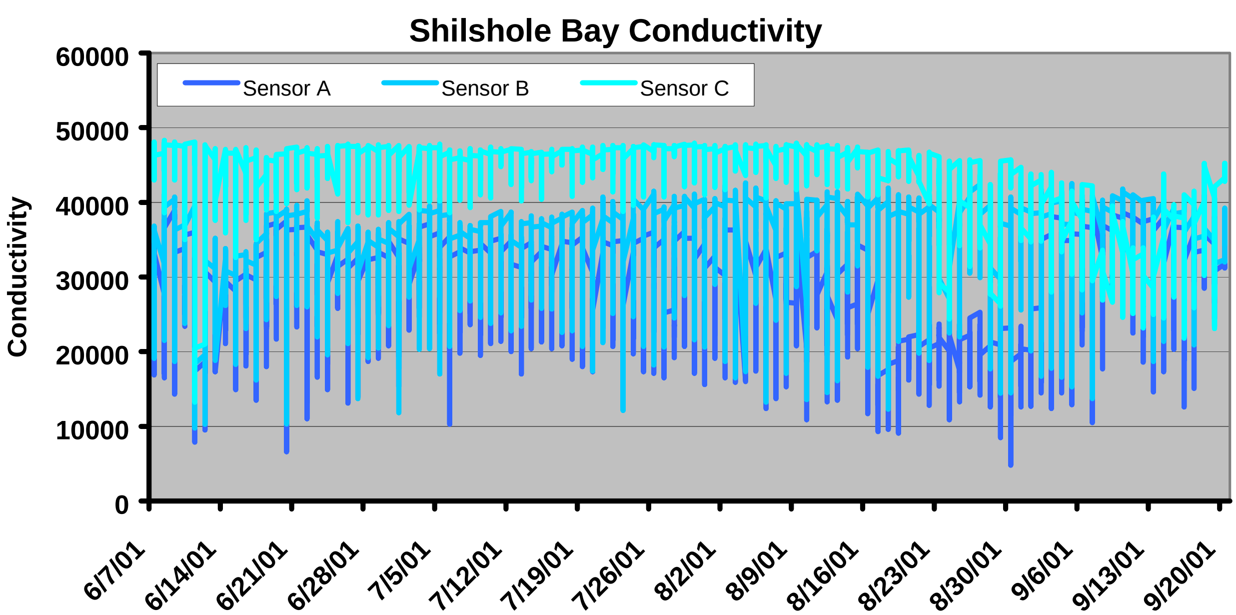



r2=0.11
Salinity at 0.5 m (ppt)
22
21
20
19
18
17
16
15
0
100
200
300
400
500
Flume Volume (cfs)


r2=0.68
Salinity at 1.5 m (ppt)
24
23
22
21
20
19
18
17
0
100
200
300
400
500
Flume Volume (cfs)


r2=0.50
Salinity at 4 m (ppt)
32
31
30
29
28
27
26
0
100
200
300
400
500
Flume Volume (cfs)


Shilshole Bay Hourly Temperature June 7-September 20
Temperature (F)
70
68
66
64
62
60
58
56
54
52
50
0.5 m
1.0 m
4.0 m
6/7/01
6/14/01
6/21/01
6/28/01
7/5/01
7/12/01
7/19/01
7/26/01
8/2/01
8/9/01
8/16/01
8/23/01
8/30/01
9/6/01
9/13/01
9/20/01


Shilshole Bay Conductivity
Conductivity
60000
50000
40000
30000
20000
10000
0
Sensor A
Sensor B
Sensor C
6/7/01
6/14/01
6/21/01
6/28/01
7/5/01
7/12/01
7/19/01
7/26/01
8/2/01
8/9/01
8/16/01
8/23/01
8/30/01
9/6/01
9/13/01
9/20/01